AIR COMMAND AND STAFF COLLEGE

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AIR COMMAND AND STAFF COLLEGE

AN ANALYSIS OF THE RC-135-S AIRBORNE OPTICAL TRACKING SYSTEM

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ABSTRACT

The RC-135-S aircraft has been plagued with optical tracking and boresight problems for a number of years. These problems are compounded because of the requirement for narrow field of view instruments under one degree. This study analyzes the cause and extent of these problems and concludes that the servo system is not satisfactory for one degree field of view instruments. The author recommends several changes to system design and operating procedures for improved tracking accuracy, reliability, and boresighting.

PREFACE

This study analyzes alignment problems of the RC-135-S Airborne Optical Tracking System. These problems have plagued this system for a number of years. The results have been a serious reduction in collection capability on narrow field of view instruments and lowered overall confidence in the system.

The author is interested in solving this problem because he feels it is within his capability and important to national security. He has operated, maintained, and analyzed this system for more than two years. As an RC-135-S crew member, he flew 67 operational sorties and accumulated over 600 flying hours. This is more than twice the normal experience level. Due to security restrictions, he is the only operator to evaluate this system under operational conditions. He was also responsible for writing the first classified technical operators manual on RC-135-S Airborne Optical Tracking Systems. The author has nine years experience as an Electronic Warfare Officer and holds a certified Federal Aviation Agency Airframe and Powerplant License (No. 1434489).

Special recognition is due Mr. John V. Tumas, who is an Optical Systems Engineer with Ling Tempco Vought Electrosystems in Greenville, Texas. Without Mr. Tumas' assistance this study would not have been possible.

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CHAPTER I

INTRODUCTION

Background

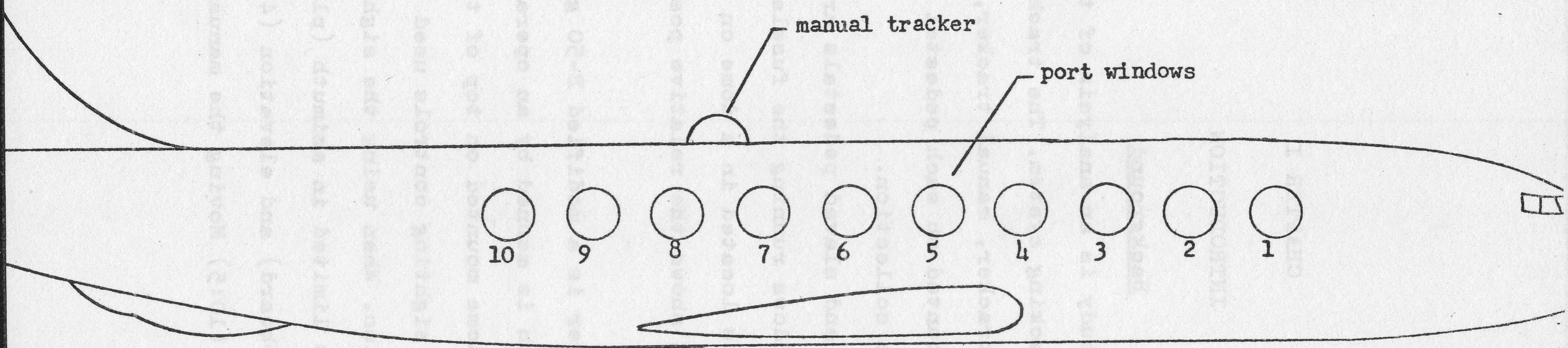
This research study is an analysis of the RC-135-S airborne optical tracking system. The tracking system consists of an autotracker, manual tracker, and nine slaved pedestals. Mounted on each pedestal are optical instruments for data collection.

The autotracker and slaved pedestals are positioned in front of port windows running the fuselage length. The manual tracker is located in a dome on top of the fuselage. Figure 1-1 shows the relative position of each sub-system.

The manual tracker is a modified B-50 gunsight.(10:3) This tracker position is manned by an operator who sits directly beneath a dome mounted on top of the fuselage. Within the dome are sighting controls used by the operator for target acquisition. When using the sighting controls, the field of view is limited in azimuth (plus or minus 30 degrees from starboard) and elevation (45 degrees up and 7 degrees down).(10:5) Moving the manual tracker

Figure 1-1

RC-135-S Position Profile



Note:
autotracker in position #5
slaved pedestals in position # 2, 3, 4, 6, 7, 8, 9, 10
position # 1 not applicable

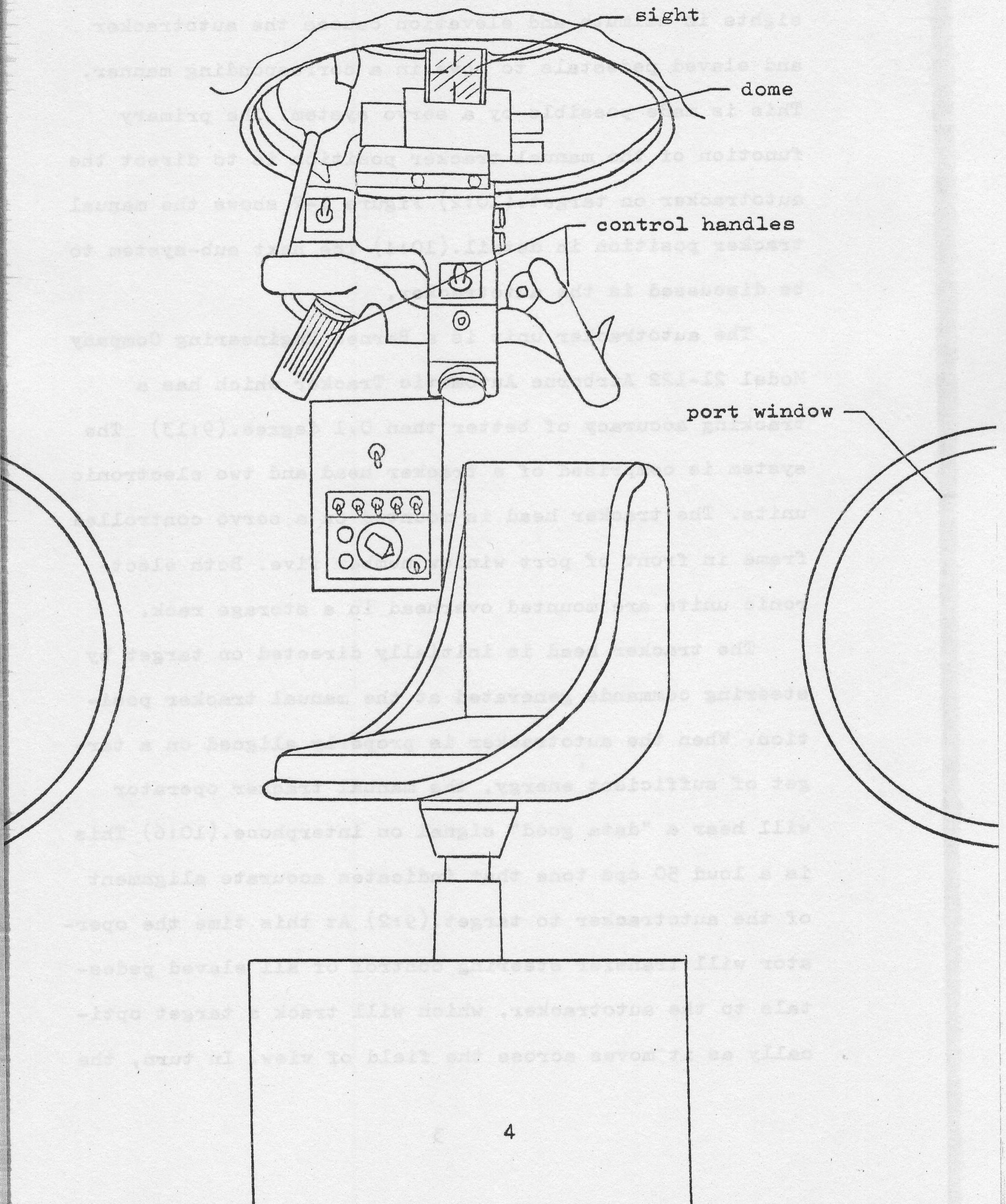
sights in azimuth and elevation causes the autotracker and slaved pedestals to move in a corresponding manner. This is made possible by a servo system. The primary function of the manual tracker position is to direct the autotracker on target.(10:2) Figure 1-2 shows the manual tracker position in detail.(10:4) The next sub-system to be discussed is the autotracker.

The autotracker unit is a Barnes Engineering Company Model 21-122 Airborne Automatic Tracker which has a tracking accuracy of better than 0.1 degree.(9:13) The system is comprised of a tracker head and two electronic units. The tracker head is mounted on a servo controlled frame in front of port window number five. Both electronic units are mounted overhead in a storage rack.

The tracker head is initially directed on target by steering commands generated at the manual tracker position. When the autotracker is properly aligned on a target of sufficient energy, the manual tracker operator will hear a "data good" signal on interphone.(10:6) This is a loud 50 cps tone that indicates accurate alignment of the autotracker to target.(9:2) At this time the operator will transfer steering control of all slaved pedestals to the autotracker, which will track a target optically as it moves across the field of view. In turn, the

Figure 1-2

Manual Tracker Position



autotracker provides error signals to nine ser... rolled slaved pedestals. Before explaining how this ... nal is used by each pedestal, the pedestal configuration will be discussed.

The slaved pedestals are mounted in front of port windows 2,3,4,6,7,8,9, and 10. Servo motors are used to move the pedestals in both azimuth and elevation. Mounted on each pedestal is a cluster of optical instruments that record target characteristics. Many of these instruments have a narrow field of view (under 1^{o}) and require very accurate tracking.

The slaved pedestals get their pointing direction from the autotracker or manual tracker command signal.(9:2) In this study our concern is with the autotracker. This signal causes the servo motors to move the pedestals in both azimuth and elevation. Pedestal movement must coincide exactly with autotracker movement for accurate tracking of all optical instruments and no loss of data. Any degredation in tracking accuracy and boresight alignment of the slaved pedestals to autotracker may result in complete loss of data.

Boresight alignment is accomplished under static conditions by paralleling the optical axis of all pedestal mounted instruments with the autotracker optical axis. Tracking accuracy of slaved pedestals depends on their ability to maintain boresight under dynamic conditions. Figure 1-3 illustrates this principle in azimuth. The same principle applies to elevation and provides a basis for the following problem statement.

Problem

The slaved pedestals are not accurately tracking the autotracker and are difficult to boresight. These alignment problems result in a serious loss of target data on narrow field of view instruments (under 1°). (17J:1) Tracking accuracy and boresight difficulties will be investigated in this study. The objective is as follows.

Objective

The servo system will be analyzed for possible changes that will improve tracking accuracy and boresight of slaved pedestals to autotracker. The complexity of this problem coupled with limited data and time impose several limitations.

Limitations

The limitations placed on this research study are:

1. Analysis is limited to optical tracking problems of the RC-135-S aircraft.

2. Attention is focused on the servo system for slaved pedestals #4,#10, and autotracker position #5.

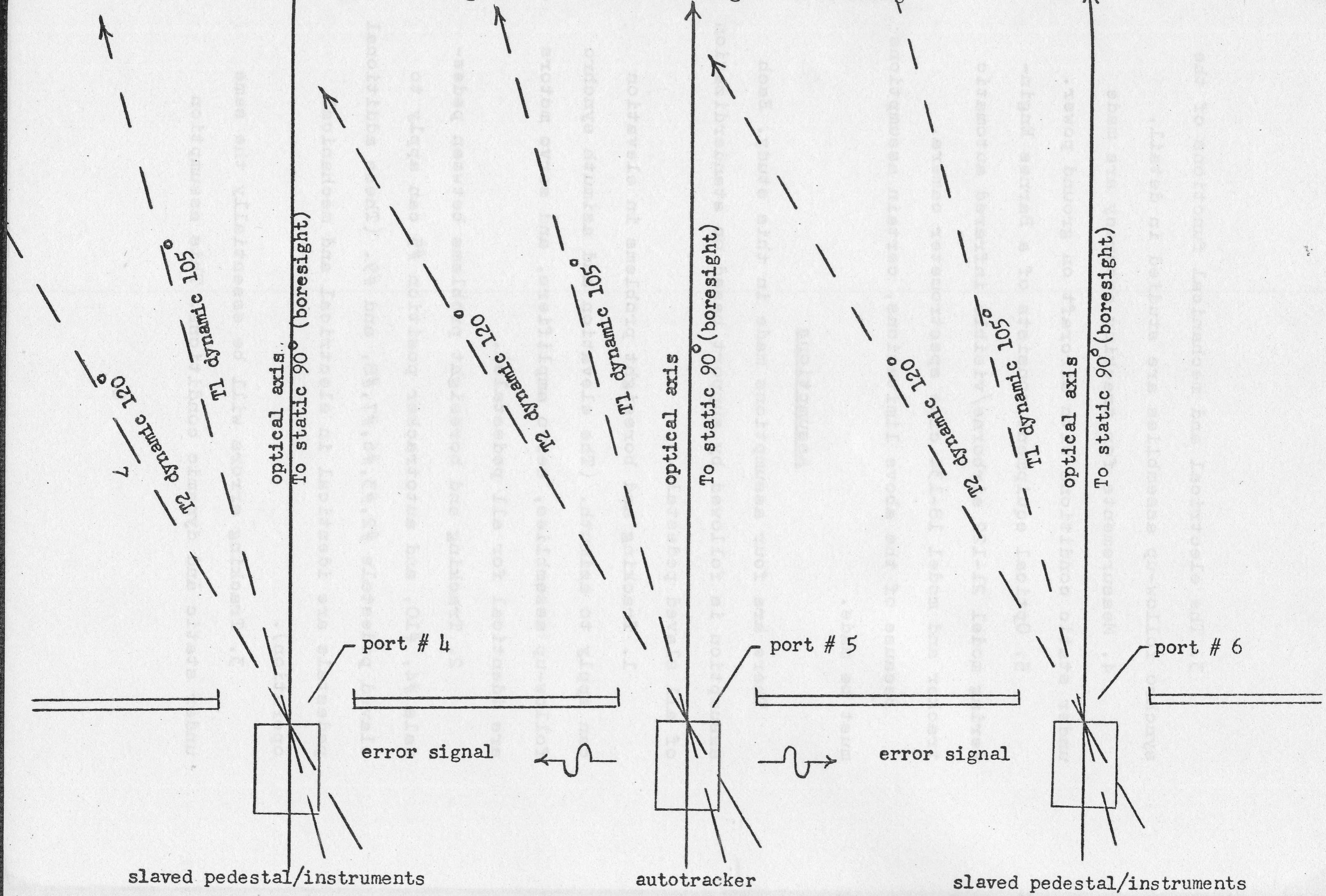


Figure 1-3 Pedestal Boresight And Tracking

3. The electrical and mechanical functions of the synchro follow-up assemblies are studied in detail.

4. Measurements for tracking accuracy are made under static conditions with aircraft on ground power.

5. Optical equipment consists of a Barnes Engineering model 21-122 airborne/visible infrared automatic tracker and model 18-134 cine spectrometer camera.

Because of the above limitations, certain assumptions must be made.

Assumptions

There are four assumptions made in this study. Each assumption is followed by support based on standardization of all slaved pedestals.

1. Tracking and boresight problems in elevation can apply to azimuth. (The elevation and azimuth synchro follow-up assemblies, servo amplifiers, and servo motors are identical for all pedestals).

2. Tracking and boresight problems between pedestals #4, #10, and autotracker position #5 can apply to slaved pedestals #2,#3,#6,#7,#8, and #9. (These additional pedestals are identical in electrical and mechanical operation).

3. Tracking errors will be essentially the same under static and dynamic conditions. This assumption

excludes the effects of pedestal lag and overshoot. (The electrical input and mechanical configuration of all slaved pedestals are the same for both static and dynamic conditions.)

4. The two servo amplifiers for each pedestal may be connected in parallel and driven by one control transformer without degrading tracking accuracy. (This arrangment was tested successfully on pedestal #9 under operational conditions in April 1968.)

The assumptions listed above are only applicable to the RC-135-S optical servo system. The sources of data will now be covered.

<u>Sources</u>

The main sources of data are the experiences and observations of the writer while assigned to the RC-135-S project. Engineering support and guidance was provided by the following individuals:

1. Mr. John V. Tumas (Optical Systems Engineer), Electro Optics section of Ling Tempco Vought Electrosystems (LTVE), Greenville, Texas.

2. Mr. Douglas Prince (Electrical Engineer), Electronics section of LTVE, Greenville, Texas.

3. Mr. Joseph Zufall (Physicist), TDDCO, Foreign Technology Division, Wright Patterson AFB, Ohio.

Additional references were obtained from the Air University Library.

Organization

The body of this report consists of four chapters. Chapter Two traces the path of "Angular Transfer" from autotracker to slaved pedestal. Chapter Three outlines the problems in determining alignment and begins a detailed examination of the first point in angular transfer. This point is a mechanical linkage and its effects on tracking accuracy are covered in detail. Chapter Four continues the discussion of angular transfer and emphasizes the problems of boresighting and the synchro follow-up assembly. The last chapter will present the author's conclusions and recommendations for improved boresight and pedestal tracking.

CHAPTER II

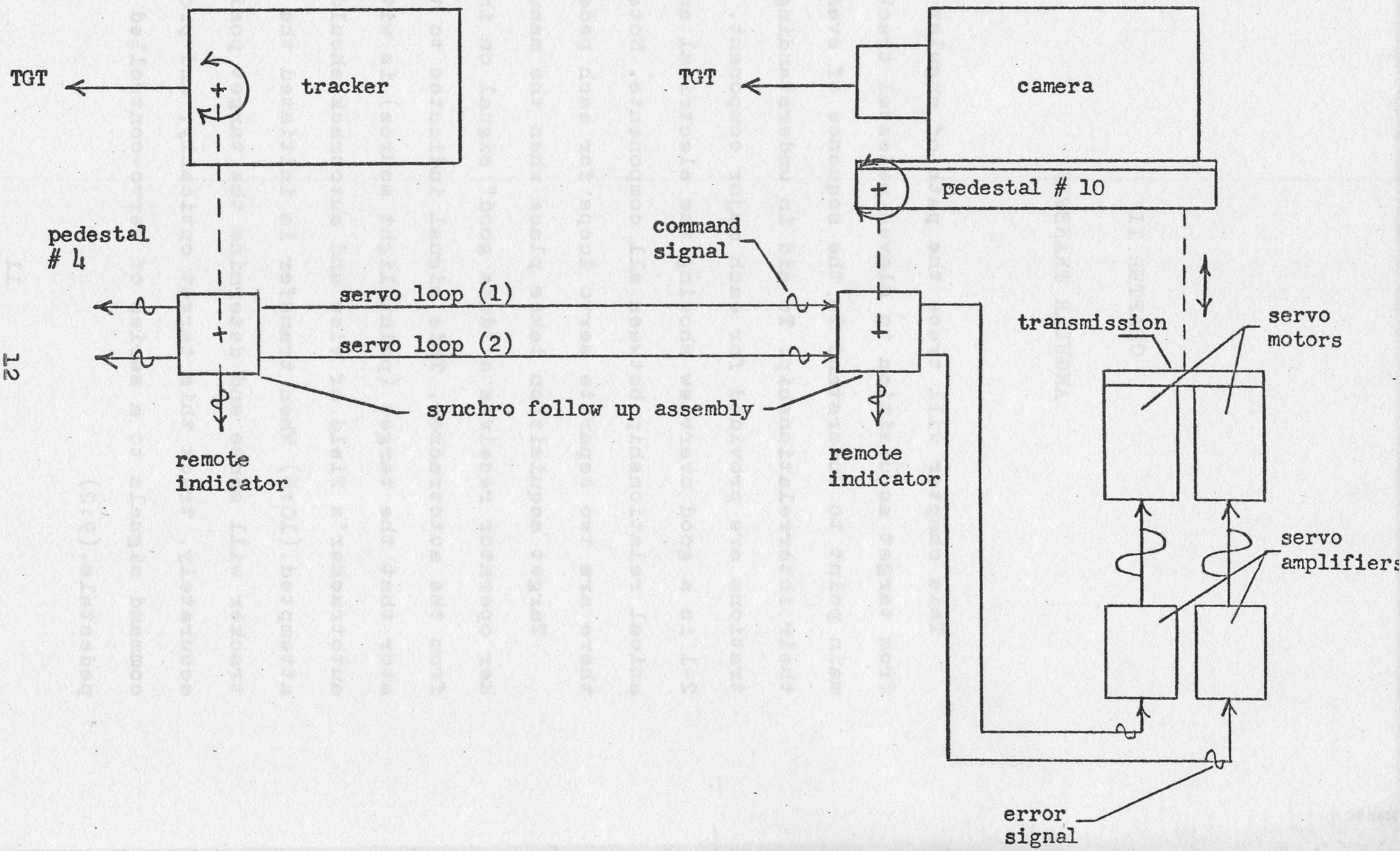
ANGULAR TRANSFER

This chapter will trace the path of angular transfer from target acquisition to slaved pedestal tracking. The main point to understand is the sequence of events and their interrelationship. To aid in understanding, illustrations are provided for each major component. Figure 2-1 is a good overview showing the electrical and mechanical relationship between all components. Note that there are two separate servo loops for each pedestal.

Target acquisition takes place when the manual tracker operator receives a "data good" signal on interphone from the autotracker. This signal indicates to the operator that the target (point light source) is within the autotracker's field of view and autotrack should be attempted.(10:6) When transfer is initiated the autotracker will sense and determine the target position very accurately, track this target optically, and provide command signals to a series of servo-controlled slaved pedestals.(9:2)

Figure 2-1

Servo System Block Diagram



Autotracker

Radiant flux from the target is collected by the optical system (Figure 2-2) and focused on a position encoding reticle assembly.(9:3) The rotating reticle modulates this signal in a manner determined by the location of the target in respect to the optical axis. The modulated signal is intercepted by one of two detectors and is converted into a modulated electrical signal. (9:2) This signal is interpreted by two electronic units that send appropriate correcting signals to the autotracker servo motors. The servo motors move the tracker head on target and maintain alignment within (0.1) degree. (9:13) Any change in azimuth and elevation will be transmitted to slaved pedestals by a servo system. A 10° increase in elevation will be traced at this time (reference Figure 2-3)

Movement of the tracker head is transferred through a linkage to the synchro follow-up assembly which converts this angle into an electrical command signal for pedestal direction. The first step in this process starts at the autotracker elevation pivot point. A linkage, consisting of a connecting rod and two pivot arms, connects this point to a synchro follow-up assembly drive gear. Five synchro control transmitter rotors (type EGC

Figure 2-2

Autotracker Optical Block Diagram

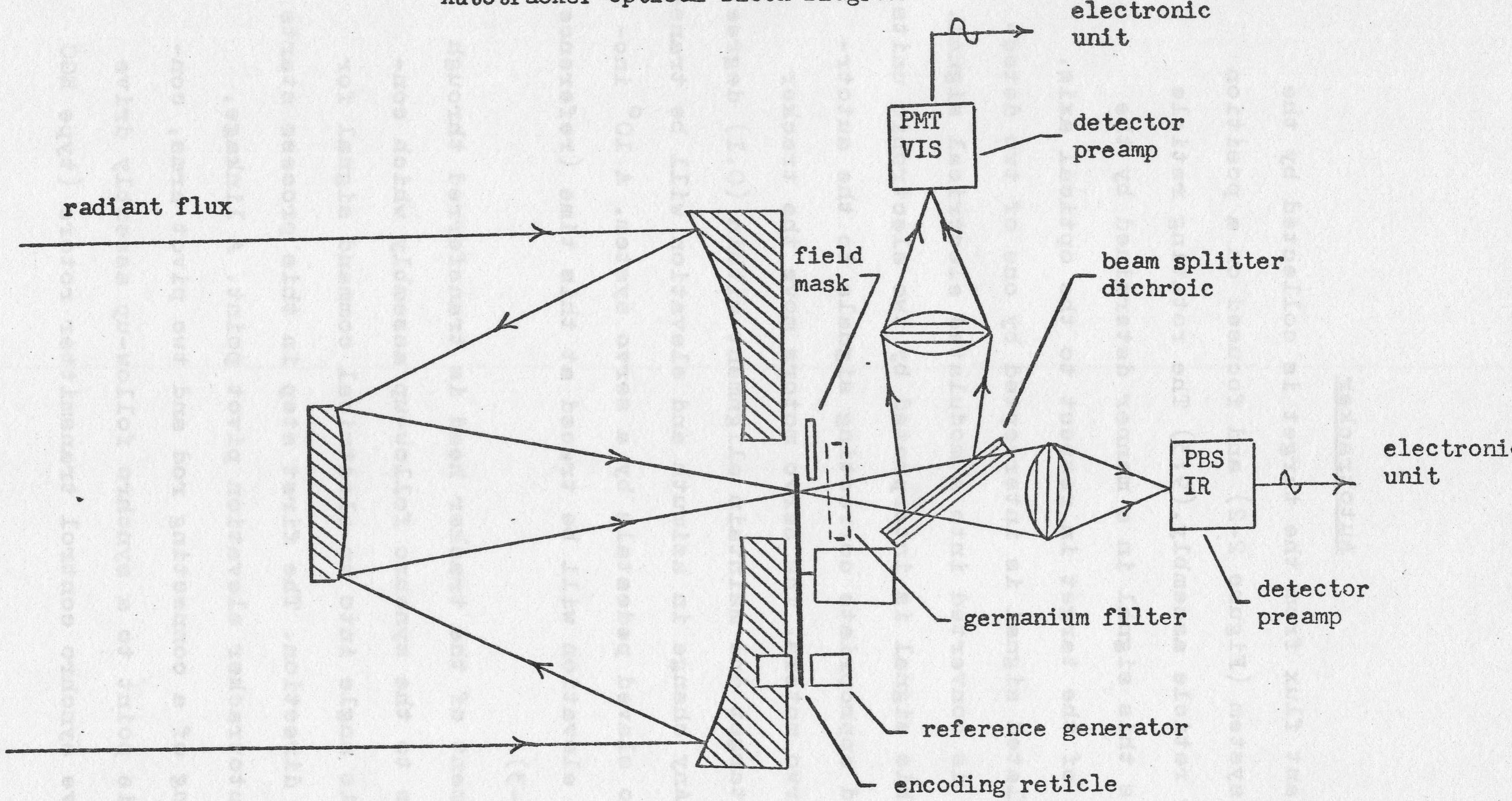
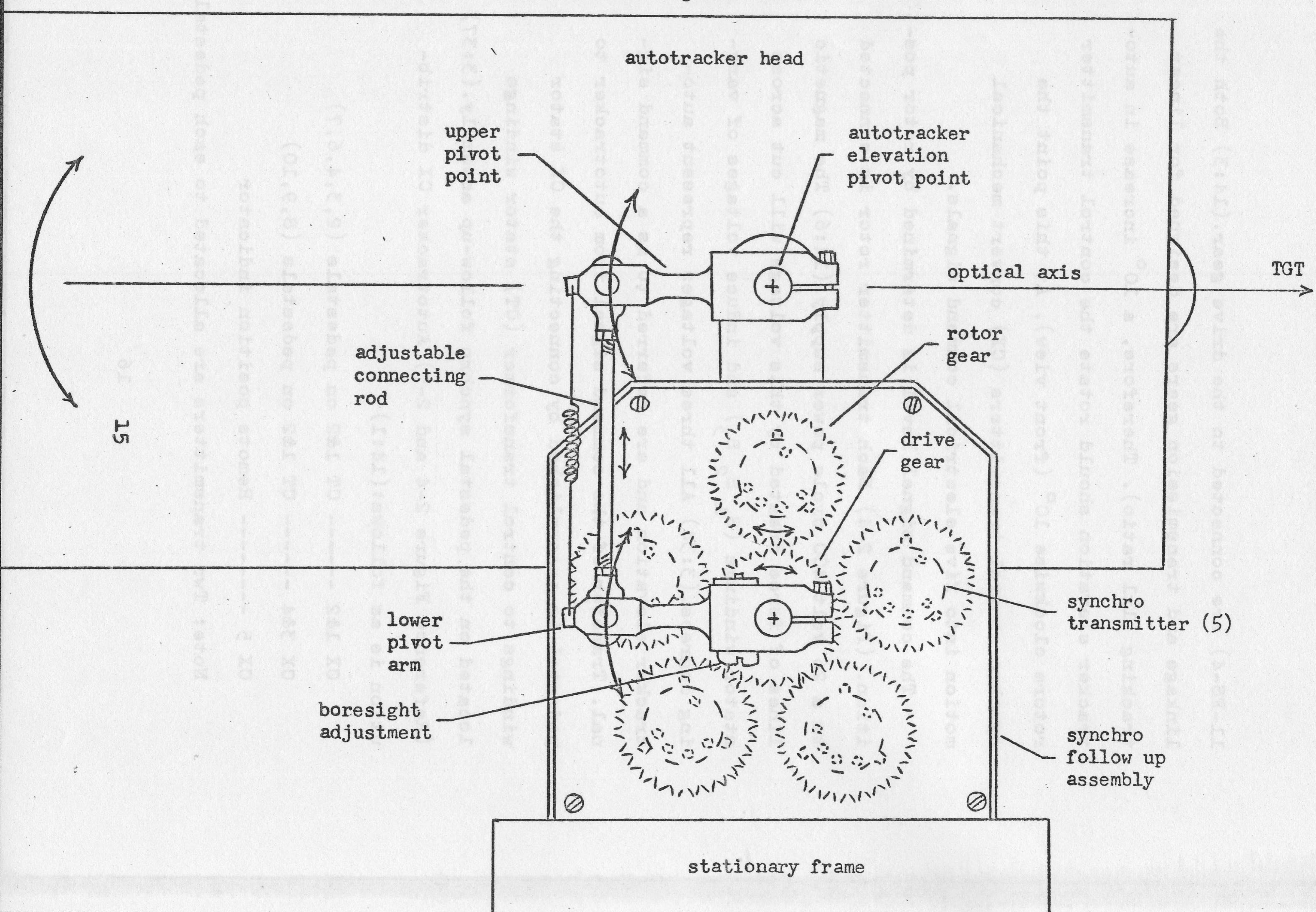


Figure 2-3

Autotracker Angular Transfer



11-FS-4) are connected to the drive gear.(14:3) Both the linkage and transmission gears are designed for linear tracking (1x1 ratio). Therefore, a 10° increase in autotracker elevation should rotate the control transmitter rotors clockwise 10° (front view). At this point the synchro control transmitters (CX) convert mechanical motion into five electrical command signals.

The command signal level is determined by rotor position. (Figure 2-4) Each transmitter rotor is connected to a 26 volt 400 cycle power supply.(14:6) The magnetic lines of force created by this voltage will cut across stator windings (S_1 S_2 S_3) and induce voltages of varying degrees.(3:34) All three voltages represent autotracker elevation and are referred to as a command signal. Transfer of the command signal from autotracker to pedestal is accomplished by connecting the CX stator windings to control transformer (CT) stator windings located on the pedestal synchro follow-up assembly.(3:37) (Reference Figure 2-4 and 2-5) Autotracker CX distribution is as follows:(14:1)

CX 1&2 ------ CT 1&2 on pedestals (2,3,4,6,7)

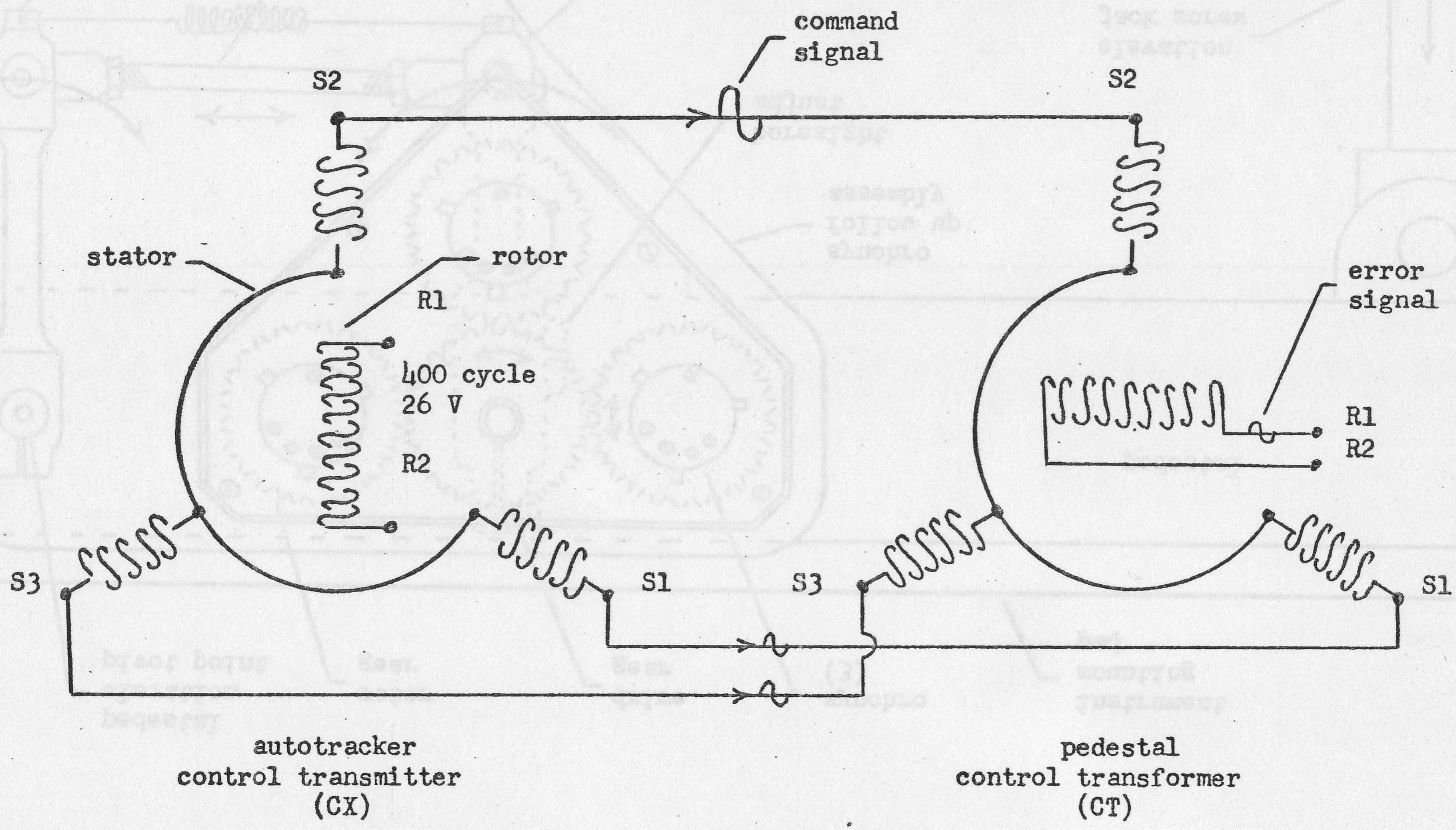
CX 3&4 ------ CT 1&2 on pedestals (8,9,10)

CX 5 -------- Remote position indicator

Note: Two transmitters are allocated to each pedestal

Figure 2-4

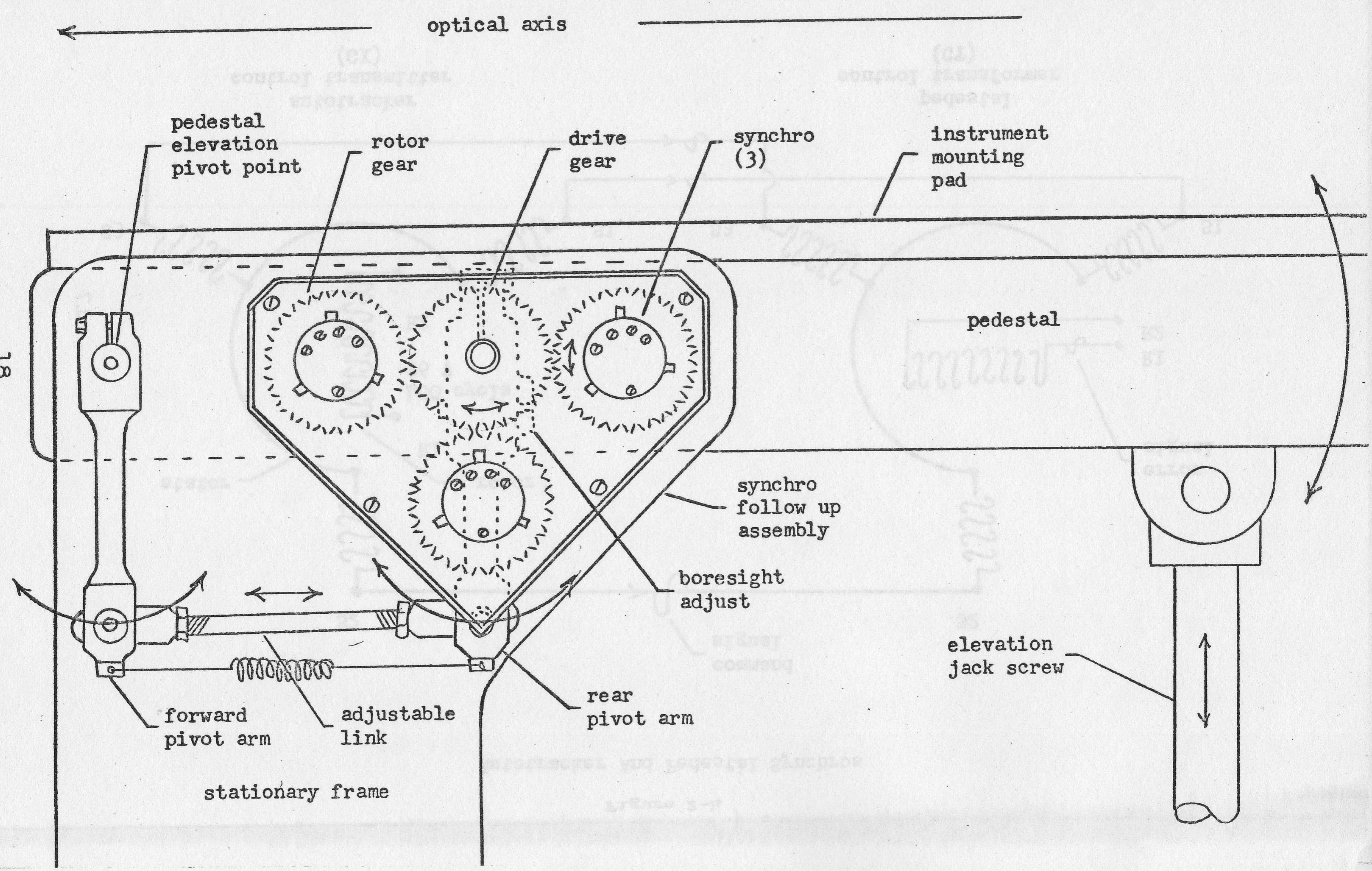
Autotracker And Pedestal Synchros



Note:
only one system shown

Figure 2-5

Slaved Pedestal Angular Transfer



because of a <u>dual</u> servo system.

At this point autotracker elevation is in the form of an electrical command signal and ready for transfer to the pedestal. The path for consideration is between the autotracker (CX 1&2) and pedestal #4 (CT 1&2).

<u>Pedestal</u>

The autotracker command signals indicating a 10° increase in elevation are impressed on the stator windings of control transformers CT 1&2. This change in stator voltages induces an error signal into the CT rotors because of the angular difference between CX and CT rotors.(7:63) The equation below reflects this relationship.(3:38)

$$E_r = E_{mr} \times \cos \theta$$

E_r = control transformer rotor output(error voltage).
E_{mr}= maximum control transformer rotor voltage.
θ = relative angle separation of CX and CT rotors.

No matter what the values are, the CT rotor output will always be zero as long as there is a 90° angular difference between rotors.(3:38) Any change will generate an error signal and result in pedestal movement. In this case the pedestal must move down 10° to reduce the error signals back to zero(null) and reestablish a 90° angular difference between rotors.

The error signal from CT 1&2 are fed into two separate servo amplifiers to provide the necessary power for servo motor control. The speed and direction of both motors will depend on the signal phase and voltage level.(3:55) At this point the two separate electrical signals are converted into one common mechanical motion. This is made possible by a transmission and jack screw. The jack screw, powered by both motors in parallel, moves the pedestal down until the error signal drops to zero. Refer to Figure 2-5 for angular transfer to the synchro follow-up assembly.

Downward movement of the pedestal is transferred through a linkage to the synchro follow-up assembly drive gear and synchro rotors. The control transmitter (CX) command signal provides input to a remote position indicator for monitoring elevation.(14:6) The linkage arrangement and gear ratios are designed to duplicate autotracker movement (1x1 ratio). Therefore, a 10° downward movement of the pedestal will cause all rotors to move in a counter clockwise direction (rear view). Pedestal movement will continue until the pedestal CT and autotracker CX rotor relationship is 90°. When this occurs the error signal will stop. Any additional changes to autotracker elevation will create a new command signal and result in additional pedestal movement.

This completes the path of angular transfer from target acquisition to pedestal tracking. The path of angular transfer from tracker to pedestal is long and complex. The accuracy of transfer is determined by linkages, synchro follow-up assemblies, amplifiers, and servo motors. These points are listed below and run in sequence from the autotracker pivot point to control transformer rotor (null). A transition point is defined as any mechanical or electrical break in the angular path that may induce tracking error. Astericks(*) represent two separate paths provided by the dual servo system.

<u>Transition Points</u>

LINKAGE	1. Autotracker pivot point Pivot arm	
	2. Pivot arm Adjustable link	
	3. Adjustable link Pivot arm	
	4. Pivot arm Drive gear shaft	← BORESIGHT ADJUSTMENT
SYNCHRO ASSEMBLY	5. Drive gear shaft Drive gear	
	*6. Drive gear Rotor gear	
	*7. Rotor gear Rotor (CX)	
	*8. Rotor (CX) Stator (CX)	

SYNCHRO ASSEMBLY

*9. Stator (CX)
Stator (CT)

*10. Stator (CT)
Rotor (CT)

*11. Rotor (CT)
Servo amplifier

*12. Servo amplifier
Servo motor

*13. Servo motor
Transmission

14. Transmission
Jack screw drive

15. Jack screw drive
Pedestal

16. Pedestal
Pedestal pivot point

LINKAGE

17. Pedestal pivot point
Pivot arm

18. Pivot arm
Adjustable link

19. Adjustable link
Pivot arm

20. Pivot arm ← BORESIGHT ADJUSTMENT
Drive gear shaft

21. Drive gear shaft
Drive gear

SYNCHRO ASSEMBLY

*22. Drive gear
Rotor gear

*23. Rotor gear
Rotor (CT)

*24. Rotor (CT)
Stator (CT)

Chapter III will examine tracking errors between the autotracker and slaved pedestals. Periodic reference should be made to Figures 2-1 and 2-5 for clarification.

CHAPTER III

DETECTION-LINKAGES

Many factors must be considered when examining tracking accuracy; however, the importance of tracking accuracy should be understood before a detailed examination is begun.

Field of View

The RC-135-S platform records many events during daylight hours with an intense sky background. Under these conditions it is very difficult to collect optical data of any quality because of film saturation. Reducing sky background interference without affecting target characteristics can be accomplished most successfully by using instruments with the narrowest possible field of view (FOV). (15:1) Instrument FOV is limited by tracking accuracy between slaved pedestals and autotracker. For example, an instrument with a one degree (1°) FOV will not collect data if permitted to drift more than a half degree ($\frac{1}{2}^{\circ}$) off target. With increased tracking accuracy, narrower FOV instruments can be used. This reduction in

FOV will increase signal to noise ratio and result in better quality data.

Detection

Normally, tracking accuracy is checked by observing autotracker and pedestal movement through the azimuth and elevation limits. Any pedestal in question can be switched into a remote position indicator at the tactical coordinator station for comparison with the autotracker. The accuracy of these measurements are only within two degrees (2°) and therefore not suitable for a one degree (1°) FOV instrument.(13:1)

Another check for tracking accuracy is the comparison of target location on film frames for a specific time. A check of this type is complex, time consuming, and requires special equipment. The difficulty in making such a check outweighs its accuracy. Because of the above factors and inadequate documentation, it is difficult to say how long tracking problems have existed. Two years would be a conservative estimate. This is based on the latest maintenance recycle conducted by LTVE in December 1967.(17J:2) The first indication of any problem resulted from a special boresight examination.

Boresight

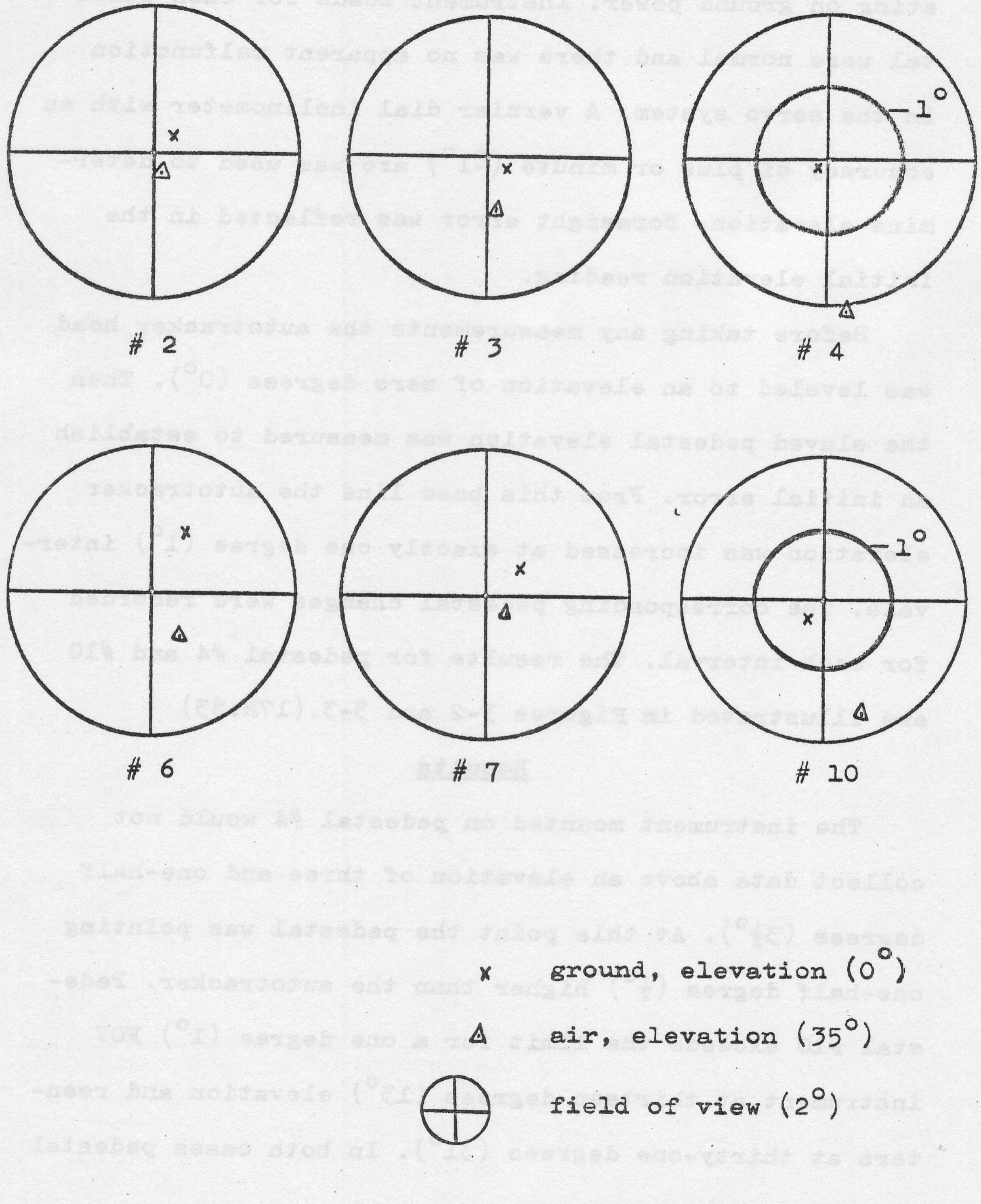
All instruments are boresighted when their optical axis are parallel in azimuth and elevation. This is accomplished by removing all film and inserting a boresight tool into the optical path. The boresight tool provides a film frame reticle and allows observation through the optics.

A boresight examination of all optical instruments was made on 26 February 1968. The objective was to determine the effects of flight on pedestal alignment. Figure 3-1 shows the relative target sightings for each instrument.(17C:47) An (x) marks the target position of ground measurements with a zero degree (0°) elevation. Airborne results are shown by a (Δ) with a thirty-five degree(35°) elevation.

The instruments mounted on pedestal #4 and #10 have a one degree (1°) field of view.(12:8) The target for pedestal #4 was six-tenths of a degree (0.6°) out of the FOV at a pointing angle of thirty-five degrees (35°) and position #10 was three-tenths of a degree(0.3°) out. Neither instrument would collect any data under these conditions. This was the first indication of nonlinear tracking. For a more complete picture of tracking, autotracker and pedestal (#4 & #10) alignment were checked at one degree (1°) intervals for a thirty-two degree (32°) change in elevation.(17H:1)

Figure 3-1

Boresight Observations



Procedure

All measurements were taken with the aircraft operating on ground power. Instrument loads for each pedestal were normal and there was no apparent malfunction in the servo system. A vernier dial inclinometer with an accuracy of plus or minute ($\pm 1^{\circ}$) arc was used to determine elevation. Boresight error was reflected in the initial elevation reading.

Before taking any measurements the autotracker head was leveled to an elevation of zero degrees (0°). Then the slaved pedestal elevation was measured to establish an initial error. From this base line the autotracker elevation was increased at exactly one degree (1°) intervals. The corresponding pedestal changes were recorded for each interval. The results for pedestal #4 and #10 are illustrated in Figures 3-2 and 3-3.(17H:63)

Results

The instrument mounted on pedestal #4 would not collect data above an elevation of three and one-half degrees ($3\frac{1}{2}^{\circ}$). At this point the pedestal was pointing one-half degree ($\frac{1}{2}^{\circ}$) higher than the autotracker. Pedestal #10 exceeds the limit for a one degree (1°) FOV instrument at thirteen degrees (13°) elevation and reenters at thirty-one degrees (31°). In both cases pedestal

Figure 3-2

Pedestal #4

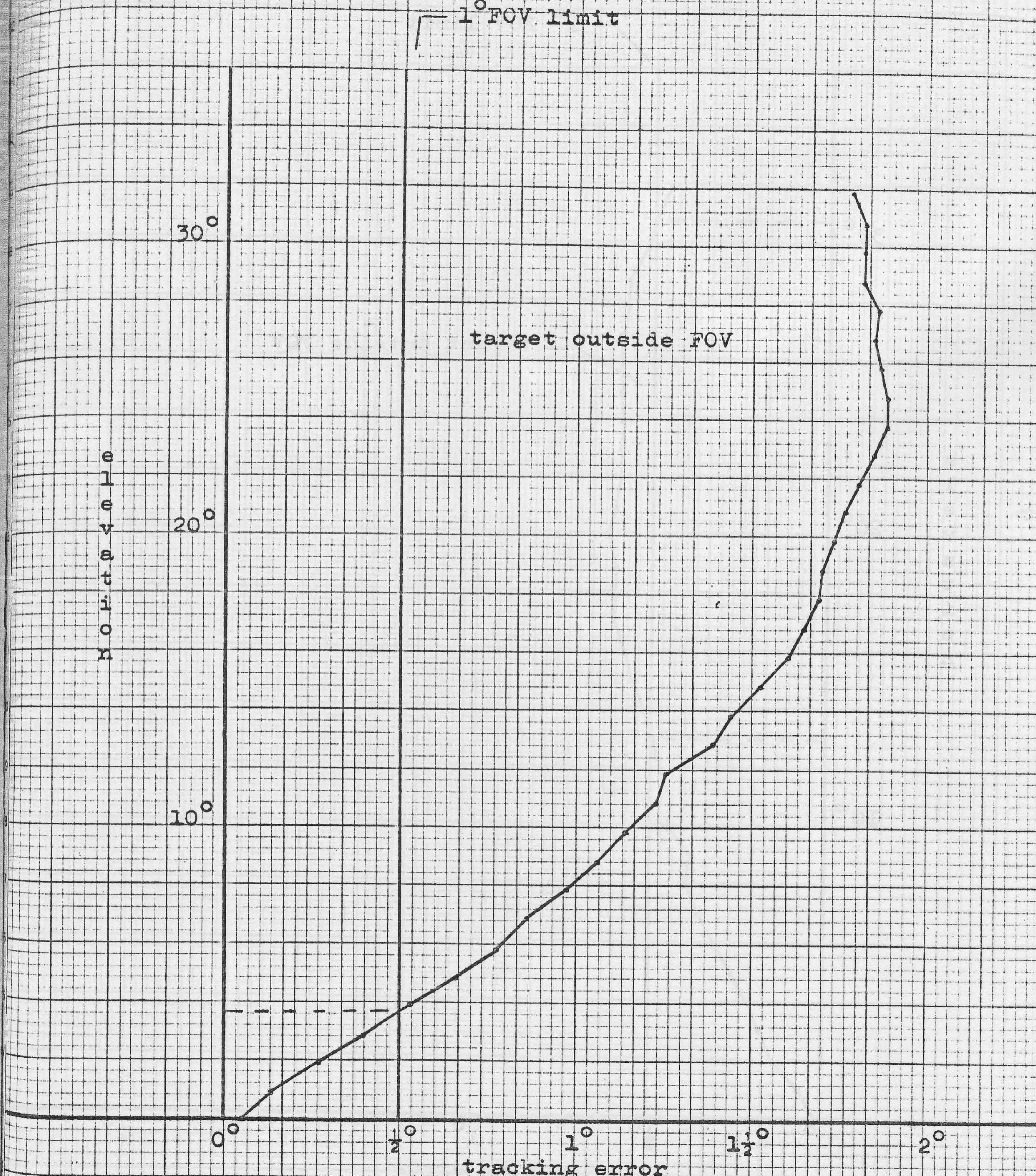
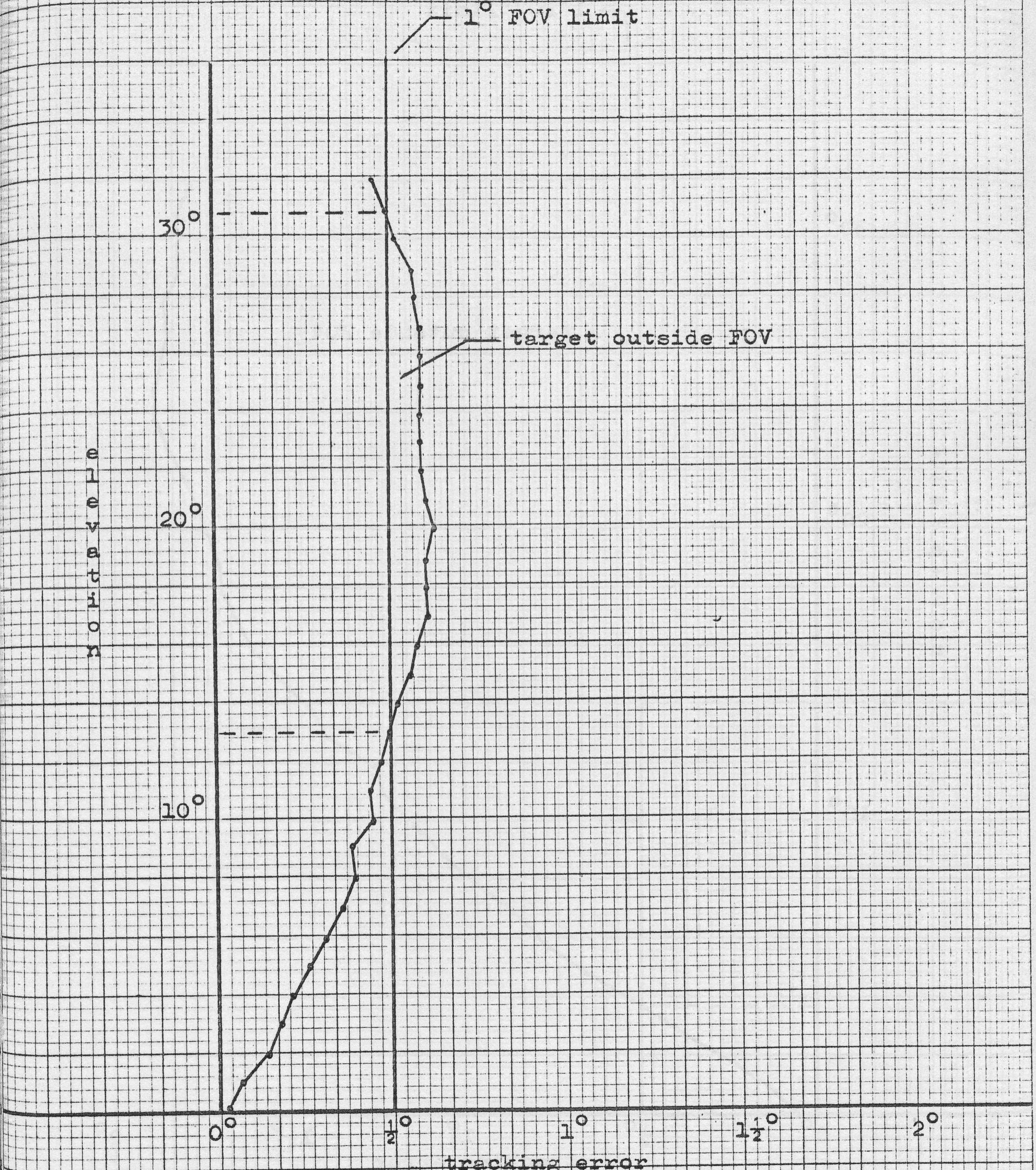


Figure 3-3

Pedestal # 10



elevation increases at a faster rate than the autotracker and tends to slow down at higher pointing angles. This is a problem of nonlinear tracking and not boresight. Several areas were investigated to find the source of this problem.

Command Signal

The first area investigated was the CT stator voltages on pedestals #2,#3,#4,#7, and #10. Any wide variances between pedestals would indicate different command signals and cause uneven tracking. Voltage measurements were taken with a Simpson Multimeter rated at twenty thousand ohms per volt (20,000Ω/volt). All synchros tested have the following characteristics:(14:3)

Type ETC-11-ES-4	Clifton Precision product
Roto resistance	370Ω
Stator resistance	56 Ω terminal to terminal
Rotor voltage	26 volts
Stator voltage	11.8 volts
Excitation	400 cycles

Table 3-1 lists the CT stator voltages of the pedestal synchro follow-up assembly for three elevation angles. From these readings the following conclusions can be made:(17D:49)

(1) The voltages for each pedestal at a given angle are relatively constant. This eliminates the possibility of a fluctuating command signal between pedestals.

Table 3-1

Control Transformer Stator Voltages

		# 2		# 3		# 4		# 7		# 10	
	Stators	CT-1	CT-2	CT-1	CT-2	CT-1	CT-2	CT-1	CT-2	CT-1	CT-2
0°	S1-S2	11.0	10.5	11.0	10.5	11.0	10.5	11.0	10.5	11.0	11.0
	S1-S3	0	0	0	0	0	0	0	0	0	0
	S2-S3	11.0	10.5	11.0	10.5	11.0	10.5	11.0	10.5	11.0	11.0
20°	S1-S2	8.2	8.0	8.2	8.0	8.2	8.0	8.2	8.0	8.2	8.1
	S1-S3	4.4	4.35	4.4	4.3	4.45	4.3	4.35	4.25	4.4	4.4
	S2-S3	12.0	12.0	12.1	12.0	12.5	12.0	12.0	11.5	12.0	12.0
40°	S1-S2	4.3	4.2	4.3	4.2	4.35	4.2	4.3	4.1	4.3	4.25
	S1-S3	8.2	8.1	8.3	8.1	8.3	8.1	8.25	8.1	8.3	8.2
	S2-S3	12.0	11.9	12.4	12.0	12.0	12.0	12.0	12.0	12.0	12.0

(2) The voltage imbalance between CT-1 and CT-2 for a given pedestal and elevation generates opposing error signals. These signals will have an adverse effect on pedestal alignment but not of the magnitude illustrated in Figures 3-2 and 3-3. An extremely large voltage imbalance would be necessary for such large errors in tracking.

At this point electrical signals are not considered a major problem but will be examined in more detail later. The next area for consideration is the synchro follow-up assembly linkage. (Refer to Figure 2-5)

<u>Linkage</u>

On 2 July 1968 the adjustable linkages for pedestal #4 and #10 were lengthened to determine their effect on tracking accuracy. The change in linkage dimensions are below.(17H:69)

(#4) changed from 4 5/8" to 4 7/8"
(#10) changed from 4 3/4" to 4 7/8"

After completing these adjustments both linkages were reinstalled and the pedestal re-checked for tracking accuracy. The results are illustrated in Figures 3-4 and 3-5.(17H:69) Both instruments are now capable of tracking through thirty degrees (30°) elevation and remaining on target. The reason for the improvement will now be explained.

Figure 3-4

Pedestal #4 Corrected

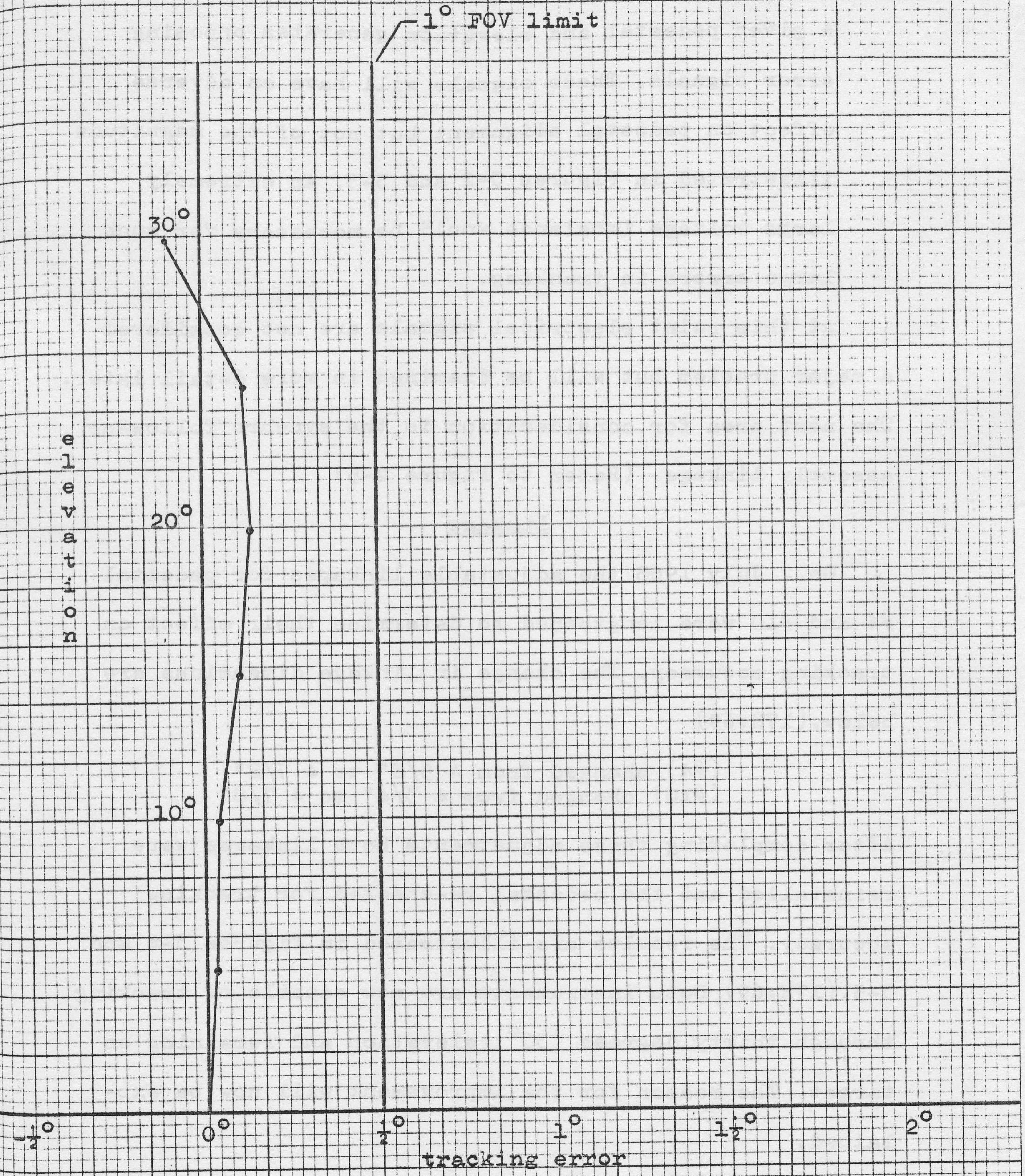
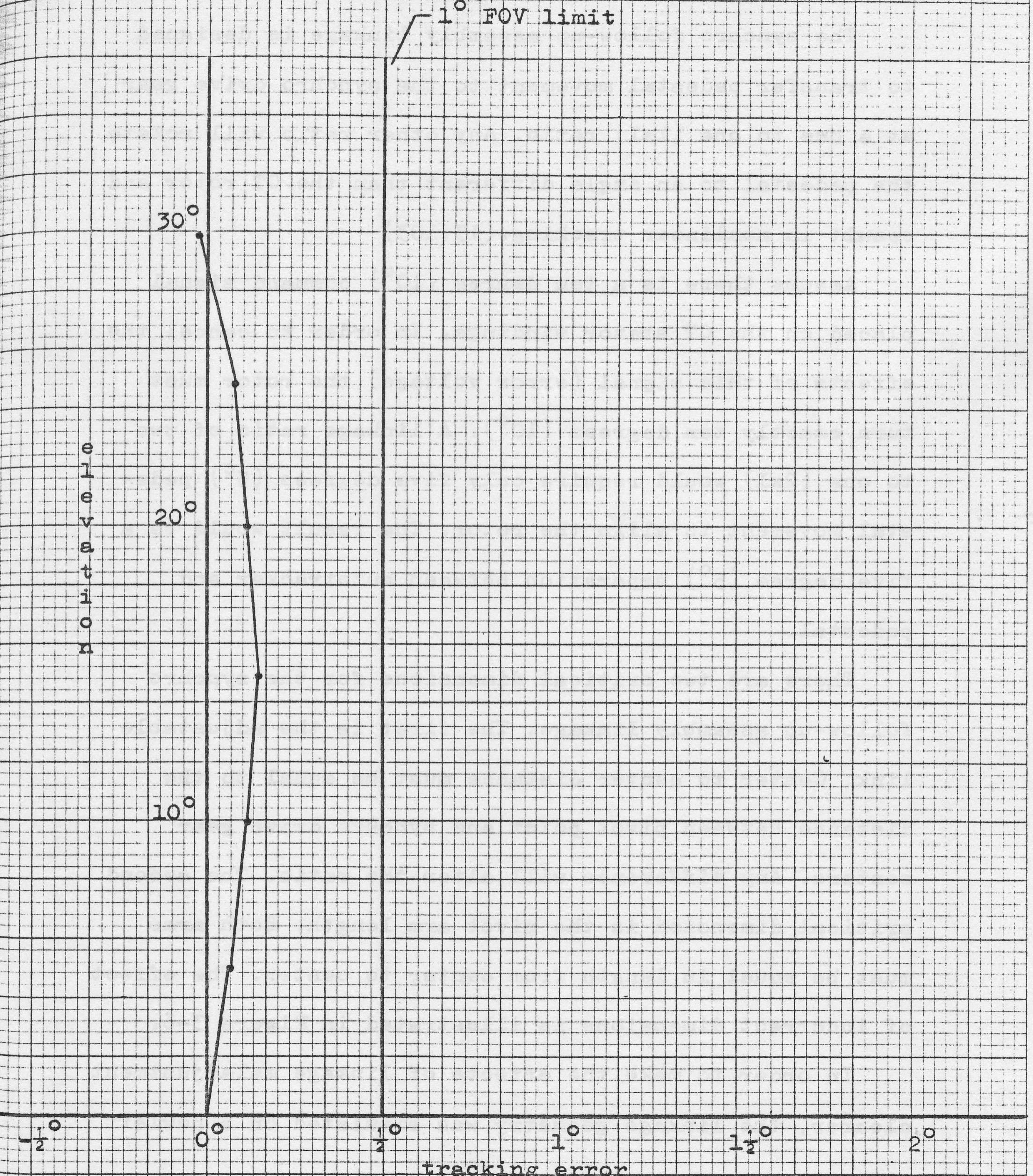


Figure 3-5

Pedestal #10 Corrected



Angular Transfer

The synchro follow-up assembly linkage is designed to transfer pedestal movement to the synchro drive gear at a one to one (1x1) ratio. Any other ratio will rotate the pedestal to an angle different than the CT rotor and result in nonlinear tracking.(13:103)

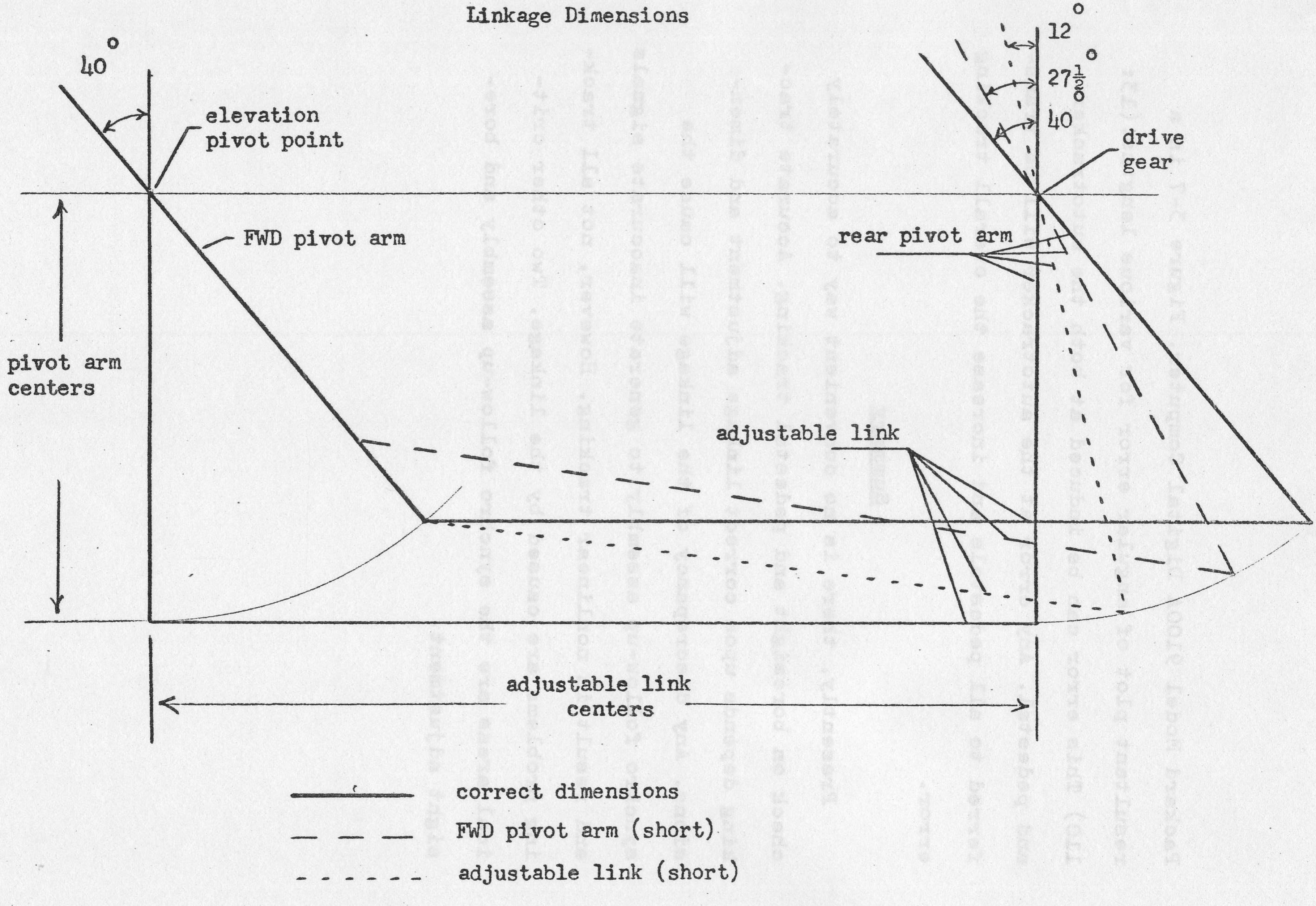
Assume there is a ten degree (10°) command signal placed on the CT stator windings. In order to cancel the effects of this signal (error voltage) the rotor must turn exactly ten degrees (10°). A linkage ratio of two to one (2x1) would require only five degrees (5°) pedestal movement to align the rotor. The result would be a five degree (5°) separation between autotracker and pedestal.

There are two critical dimensions for the synchro follow-up assembly linkage. The first is the adjustable link. Center to center distance must be equal to the distance between pivot point and synchro drive gear centers. Any difference will alter the ratio. The second critical dimension is the pivot arm length. Both arms must be equal in length from center to center. The effect of incorrect dimensions is illustrated in Figure 3-6.

In order to make the effects of linkage maladjustment clearer, the linkage geometry was simulated on a Hewlett

Figure 3-6

Linkage Dimensions



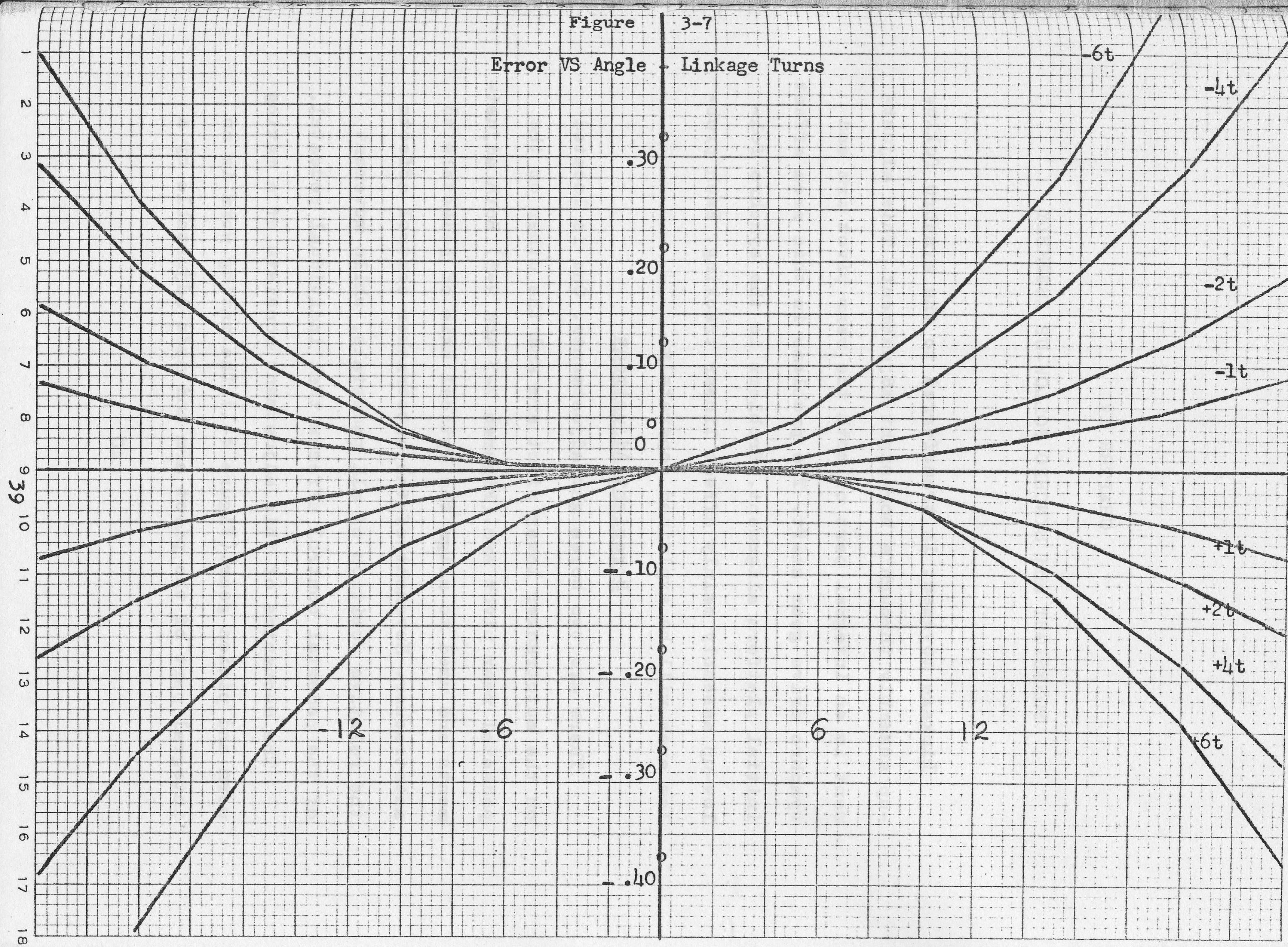
Packard Model 9100A Digital Computer. Figure 3-7 is a resultant plot of angular error for various lengths.(13: 110) This error can be induced at both the autotracker and pedestal. Any error at the autotracker will be transferred to all pedestals and increase the overall tracking error.

Summary

Presently, there is no convenient way to accurately check on boresight and pedestal tracking. Accurate tracking depends upon correct linkage adjustment and dimensions. Any discrepancy of the linkage will cause the synchro follow-up assembly to generate inaccurate signals and result in nonlinear tracking. However, not all tracking problems are caused by the linkage. Two other critical areas are the synchro follow-up assembly and boresight adjustment.

Figure 3-7

Error VS Angle - Linkage Turns



CHAPTER IV

BORESIGHT and SYNCHRO FOLLOW-UP ASSEMBLY

Linkage movement is transferred to the synchro follow -up assembly through a boresight adjustment. This adjustment is an integral part of both the rear pivot arm and synchro drive gear shaft. The problems in this area affect initial platform alignment. Problems in the synchro follow-up assembly mainly affect linear tracking. Each problem area will be explained separately.

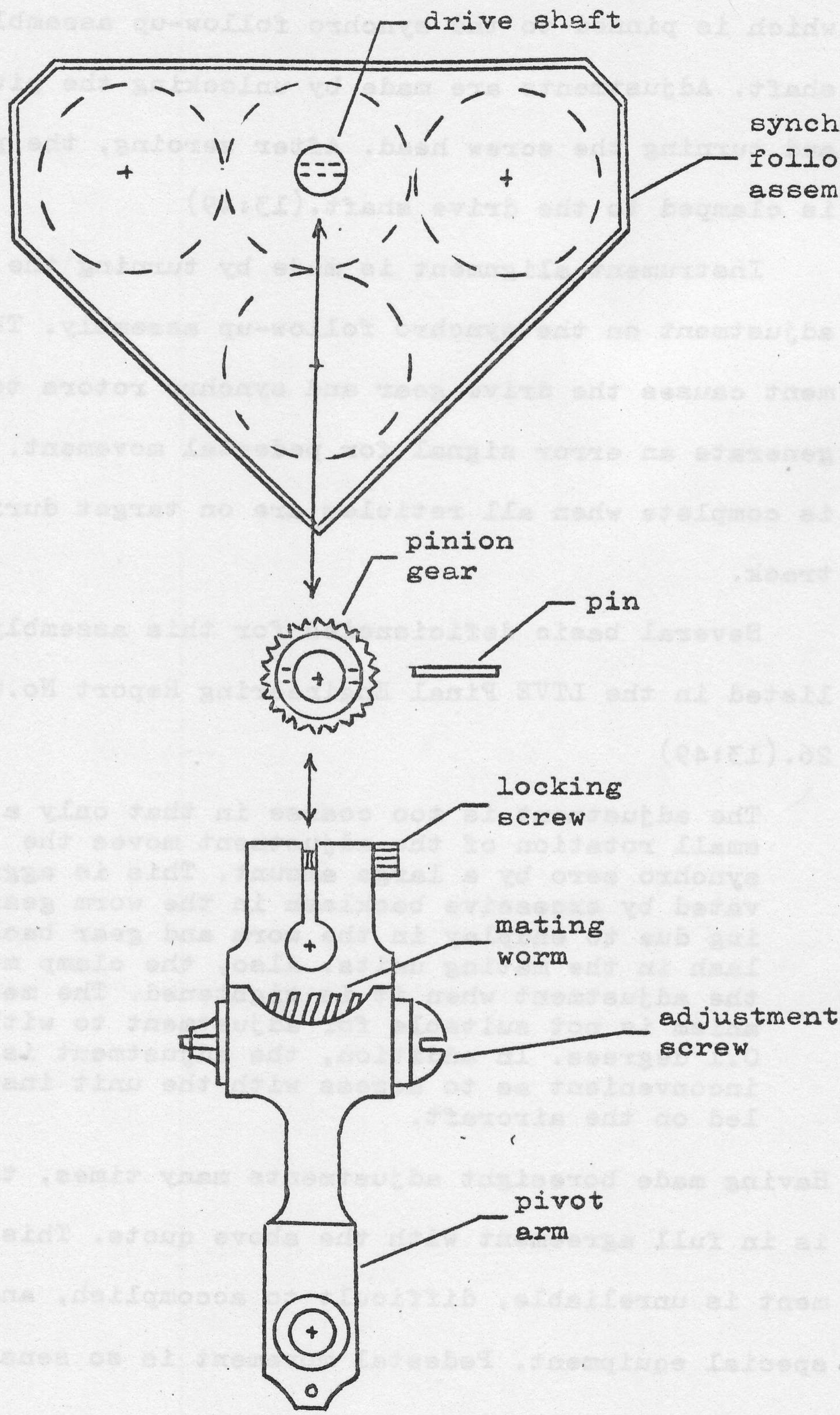
Boresight Adjustment

There are two boresight adjustments. One is located on the autotracker lower pivot arm and the other on the pedestal rear pivot arm.(Figures 2-3 and 2-5) Both adjustments are used to align the optical axis of pedestals to autotracker. Movement of the autotracker control affects the relative position of all pedestals, while movement of the pedestal control affects that individual pedestal.

The mechanics of this adjustment consists of a mating worm and pinion gear.(Figure 4-1) The mating worm is an integral part of the pivot arm and made adjustable by a

Figure 4-1

Boresight Adjustment



screw head. This worm is then mated to the pinion gear which is pinned to the synchro follow-up assembly drive shaft. Adjustments are made by unlocking the pivot arm and turning the screw head. After zeroing, the pivot arm is clamped to the drive shaft.(13:49)

Instrument alignment is made by turning the boresight adjustment on the synchro follow-up assembly. This adjustment causes the drive gear and synchro rotors to turn and generate an error signal for pedestal movement. Boresight is complete when all reticles are on target during auto-track.

Several basic deficiencies for this assembly were listed in the LTVE Final Engineering Report No.G8604.00.26.(13:49)

> The adjustment is too coarse in that only a small rotation of the adjustment moves the synchro zero by a large amount. This is aggravated by excessive backlash in the worm gearing due to endplay in the worm and gear backlash in the mating units. Also, the clamp moves the adjustment when it is tightened. The mechanism is not suitable for adjustment to within 0.1 degrees. In addition, the adjustment is inconvenient as to access with the unit installed on the aircraft.

Having made boresight adjustments many times, the author is in full agreement with the above quote. This adjustment is unreliable, difficult to accomplish, and requires special equipment. Pedestal movement is so sensitive that it requires the attention of two people. While one person is sighting through the instrument optics, the other is making adjustments. Any error in this adjustment is transferred to the synchro follow-up assembly and has a direct effect on pedestal alignment.

In addition to mechanical problems, there are two major operational limitations. The greatest limitation is target availability. A target must be bright enough to autotrack, within tracking limits, and be at least two miles away. This distance is required to eliminate parallax error. The only target presently available is a semi-portable spotlight for night use. While on the ground, stars are seldom used because of their high angles or obscuration by cloud coverage. In addition to limited targets, there is the problem of camera preparation.

Before an instrument can be boresighted, it must be downloaded and fitted with a boresight lens for sighting. (12:4) This process must be done in total darkness for internally loaded cameras (3) because of possible film exposure. When adjustments are completed the boresight tool is removed and the camers is reloaded. During this time the camera is inoperative and unavailable for use. The average down time for each camera is fifteen minutes.

Because of the excessive time the instruments are never boresighted when flying operational missions, even though instrument alignment is in question.

The next area for consideration is the synchro follow-up assembly. Chapter II covered its location, make-up, and operation in the path of angular transfer. This chapter will concentrate on its problems.

<u>Synchro Follow-Up Assembly</u>

The heart of the entire servo system discussed so far is the synchro follow-up assembly. Its primary function is to convert the autotracker position and movement into an electrical signal (error) for pedestal direction. (Refer to Chapter II) The accuracy of this signal will determine instrument field of view and collection capability. Therefore, it is extremely important to understand the cause and effect of accumulative error on tracking accuracy.

The RC-135-S optical tracking system employs two parallel single speed servo loops for each plane of rotation. Originally, this system was designed to work with instruments ranging from 40 to 153 pounds in weight and two degrees (2^{o}) or greater in field of view. (13:1) Under these requirements the system performed satisfactorily. Tracking accuracy only had to be within plus or minus one degree ($\pm 1^{\circ}$), and a parallel system increased reliability. If one servo loop failed, the other had sufficient power to continue operation with no loss of data. However, today's instrument loads and FOV requirements have altered this situation.

Instrument loads have increased to provide both day and night capability.(16:55) These increased loads now require proper operation of both servo systems.(17F:61) Failure of one servo would place excessive load on the other motor, resulting in reduced tracking accuracy or system failure. Tracking accuracy is reduced because the error signal is no longer an average of two parallel outputs(CT_1 and CT_2).(13:101) However, when these two outputs are different (out of null) they can generate a serious problem.

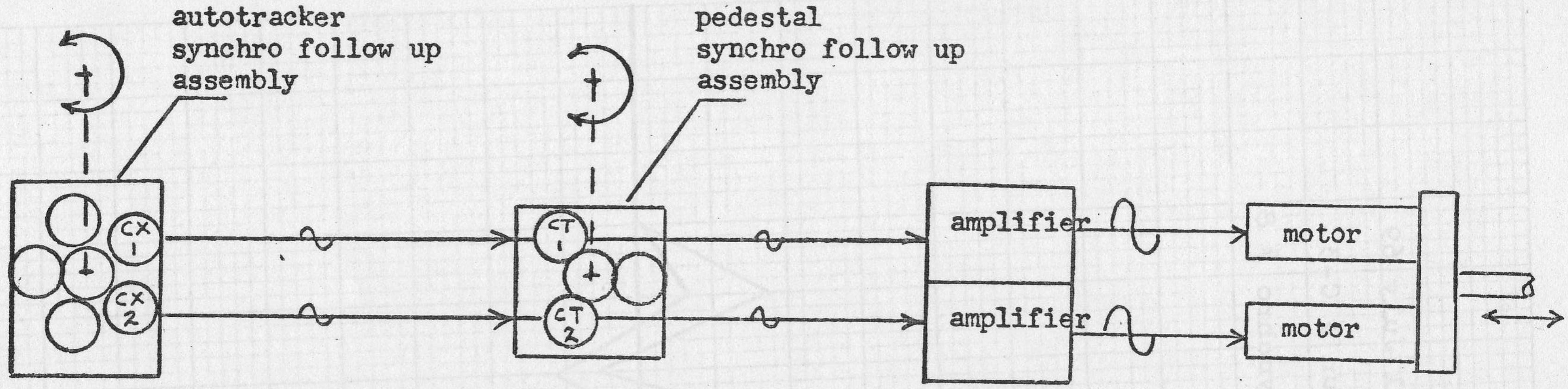
Synchro null is another problem area in this parallel servo system. A synchro that is not properly nulled will generate an imbalance between error signals and cause the two servo motors to drive against each other.(17B:35) The result is a loose pedestal and in extreme cases a completely inoperative pedestal. In April 1968 pedestal #9 would not operate properly in elevation because of inaccurate synchro alignment (out of null). The two control transformers were so far out of alignment that no meaningful signal was going to the servo amplifiers and motors. In trouble shooting this problem, one CT was disconnected and the other CT fed directly into both servo amplifiers in parallel. "This indicated that a single servo loop (as far as activating signals are concerned) will be adequate to drive both servo amplifiers."(17E:60) The servo motors are no longer opposing each other because they are driven by one common error signal. This configuration is similar to a single speed servo system and any error generated in the path of angular transfer will directly affect pedestal alignment.(3:85) In a parallel system the control transformers generate an average error signal and thereby reduce overall tracking error. Figure 4-2 illustrates the original and modified servo systems.

Tracking errors generated by the synchro follow-up assembly are caused by the gear train and synchros. Gear problems are caused by oval shapes and backlash.(1:246) Synchro problems involve oval armatures, distorted magnetic components, and spatial arrangement of magnetic windings.(2:88) The synchro tolerance for this system are (0.1°) degree.(13:6) The combined errors (gear and synchro) for an "acceptable" pedestal assembly are plotted in Figures 4-3 and 4-4.(13:102) Individual control transformer (CT) outputs are plotted in Figure 4-3. The

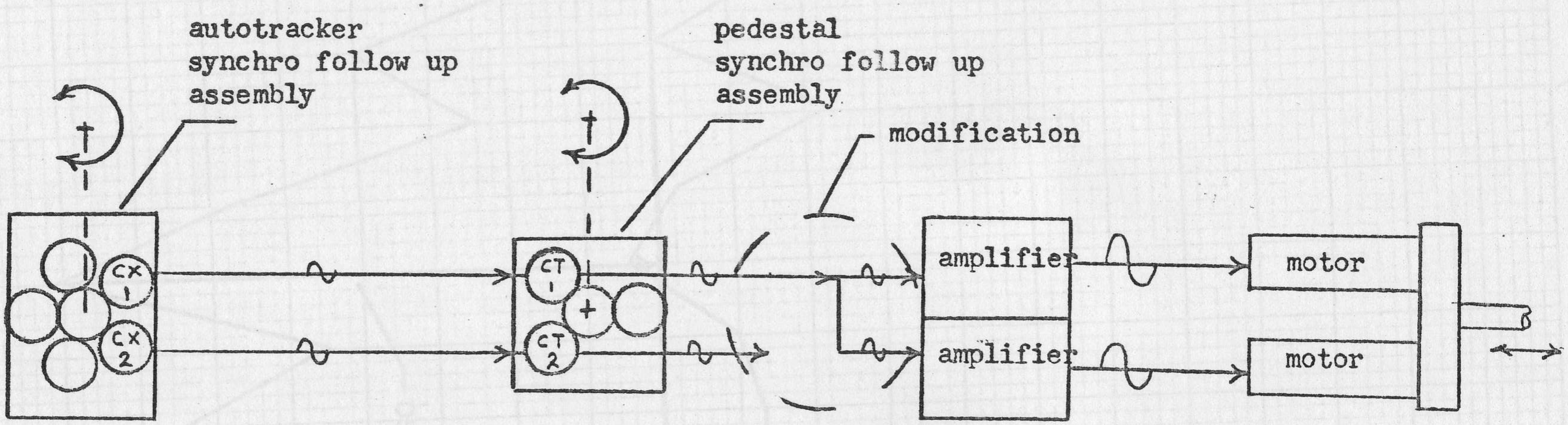
Figure 4-2

Servo Modification

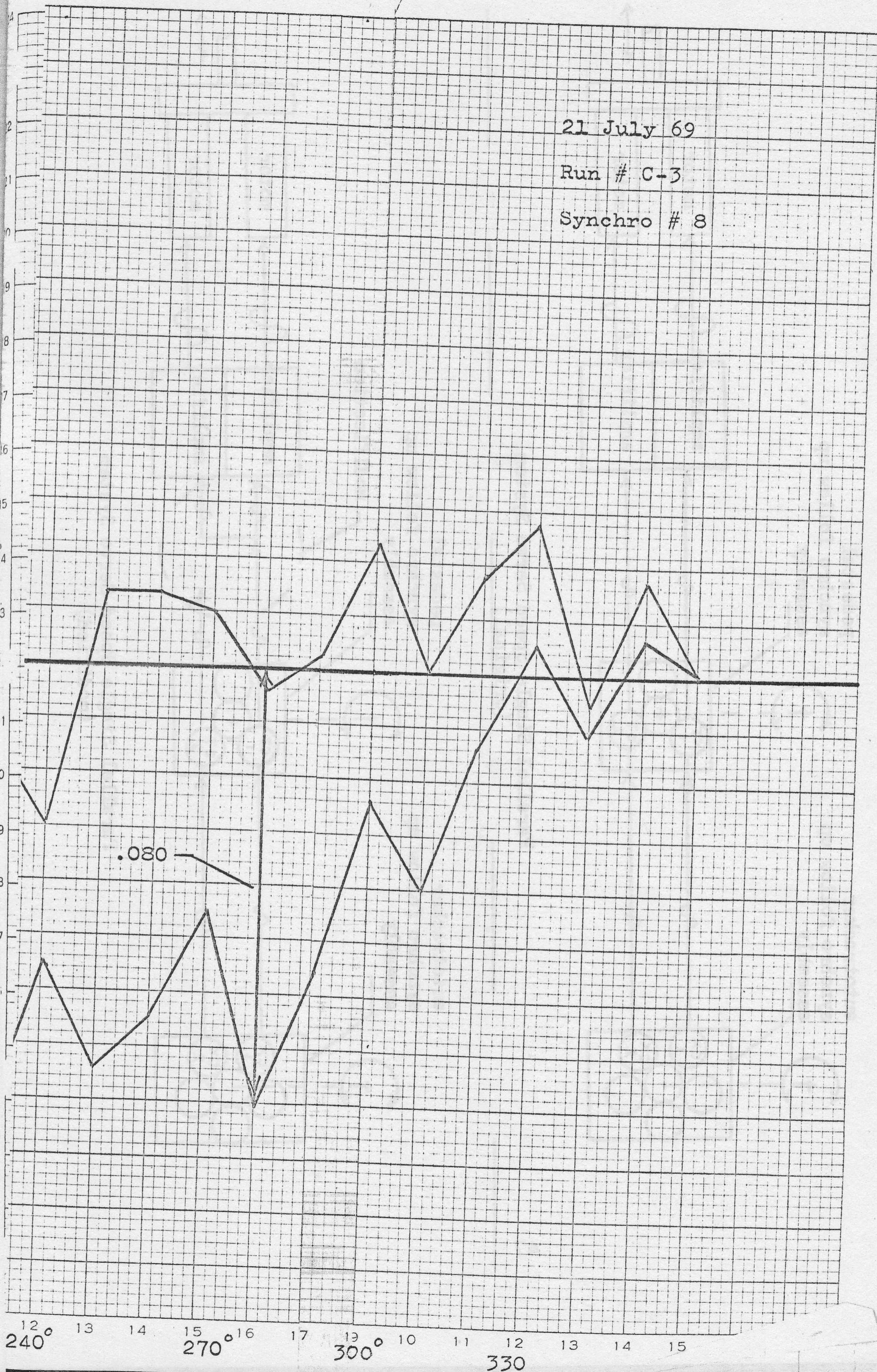
Block Diagram



Parallel Single Speed Servo System
(original)



Parallel Single Speed Servo System
(modified)



21 July 69
Run # C-3
Synchro # 8
.080
240°
270°
300°
330

gure 4-4

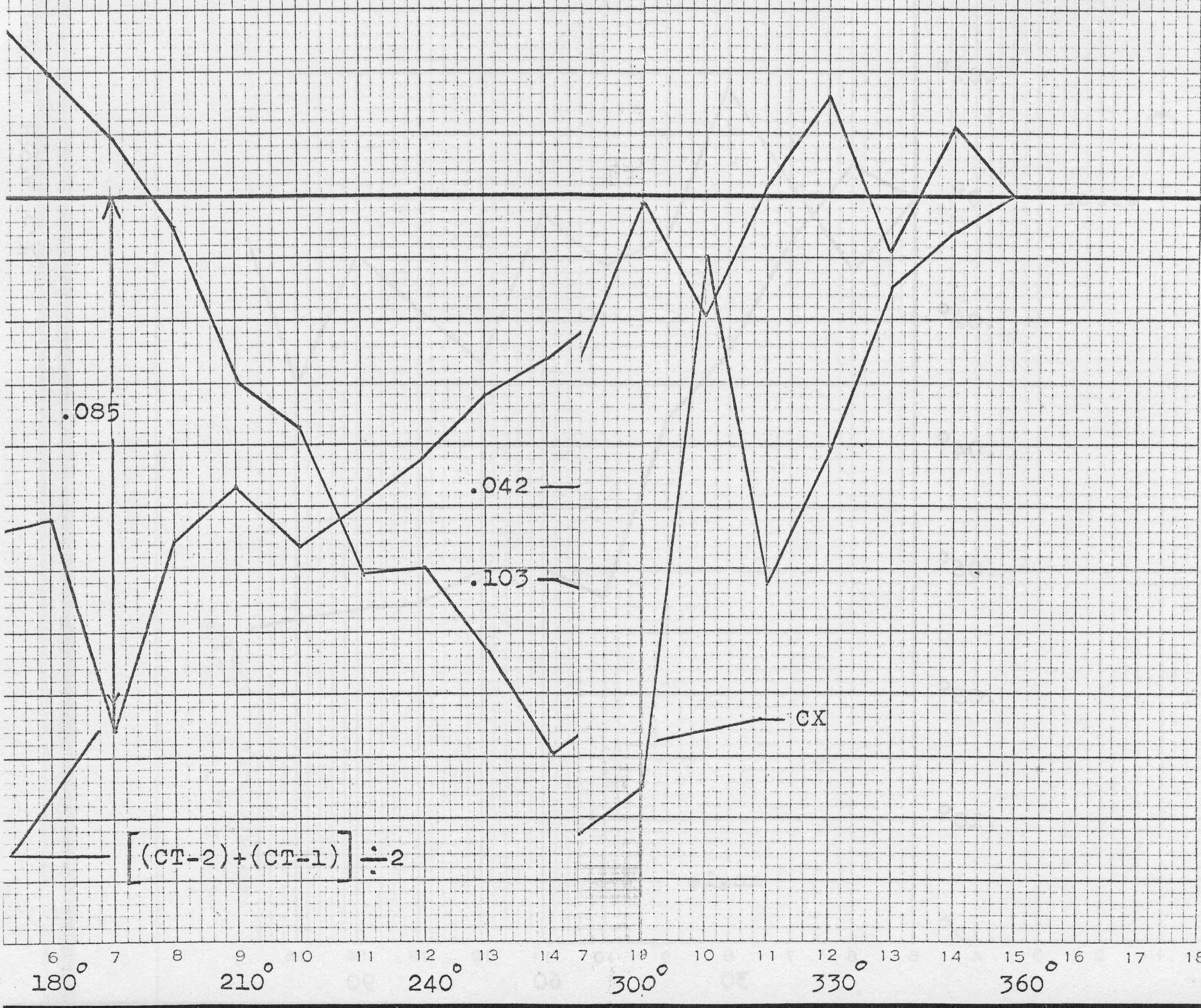
low Up Assembly

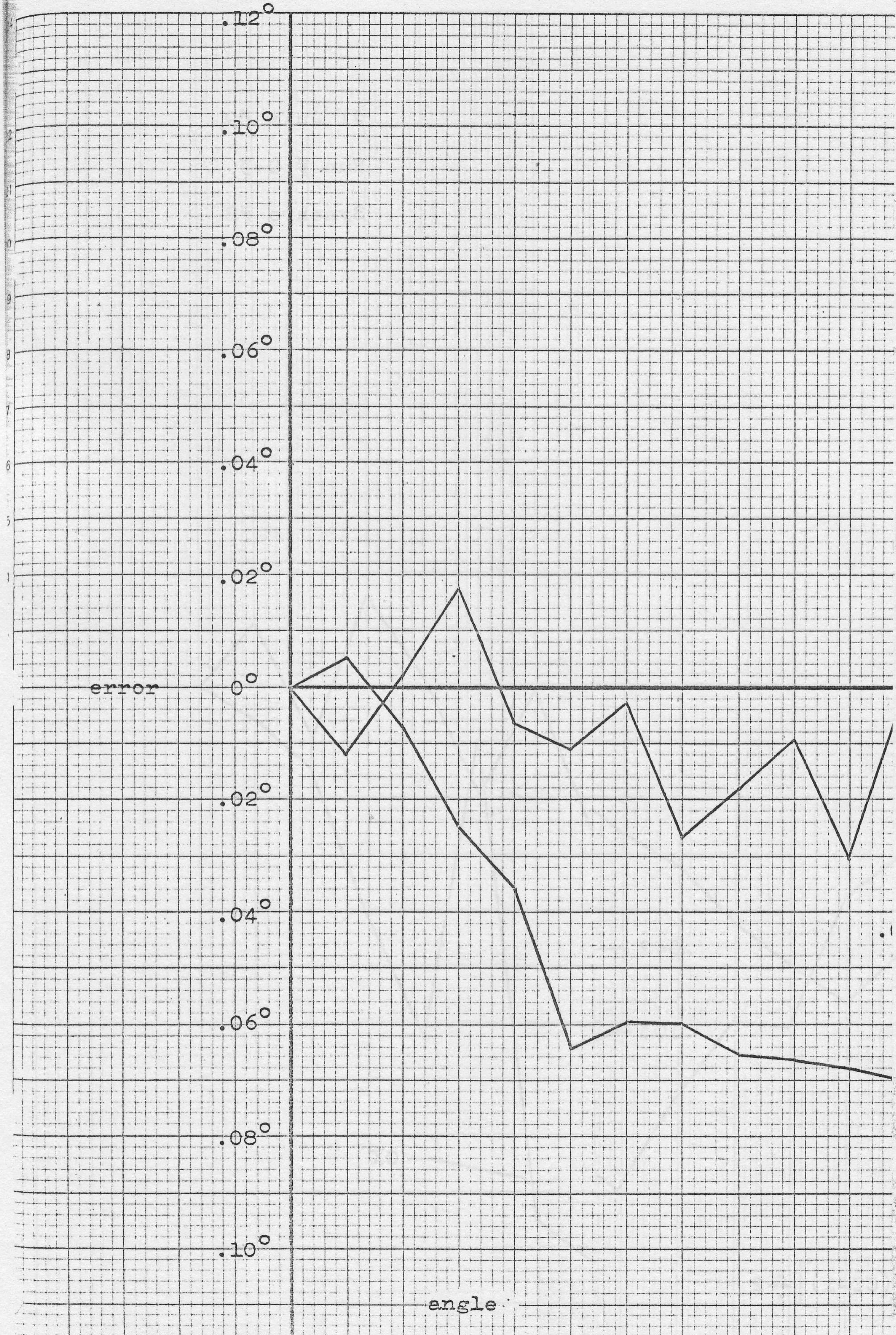
c Accuracy

21 July 69

Run # C-3

Synchro #8





.12°
.10°
.08°
.06°
.04°
.02°
error
0°
.02°
.04°
.06°
.08°
.10°
angle
.12°
30
60
90

average CT and control transmitter (CX) outputs are plotted in Figure 4-4. These plots are the results of a recent static accuracy test by LTVE.(13:96) Extracts of this test are located in Appendix A, page 62. The author's deductions from this test are as follows:

1. The control transmitter (CX) error of (0.103°) degree could represent the output of an "acceptable" autotracker follow-up assembly CX. The synchro (type EGC-11-FS-4) and gear trains (anti-backlash and 1x1 ratio) are identical.(Figure 4-4)

2. The maximum tracking error contribution with both servo loops operating is (0.085°) degree.(Figure 4-4) Note: This excludes the effects of any autotracker control transmitter (CX) input error.

3. The combined CT and CX errors at 280° in Figure 4-4 would contribute (0.145°) degree error to tracking accuracy. Note: This demonstrates the effect of autotracker CX input error with two "acceptable" assemblies.

4. The combined CT-1 and CX errors at 120° in Figures 4-3 and 4-4 would contribute (0.180°) degree error to tracking accuracy when CT-2 is inoperative. It should be noted that this demonstrates the effect of autotracker CX input error when configured as a single speed servo system.

5. The combined CT-2 and CX errors at 280° in Figures 4-3 and 4-4 would contribute (0.183°) degree error to tracking accuracy when CT-1 is inoperative. This demonstrates the effect of autotracker CX input error when configured as a single speed servo system.

6. The opposing error signals of CT-1 and CT-2 in Figure 4-3 are out of null by (0.165°) degree. These opposing signals will cause the servo motors to drive against each other and result in a loose pedestal. (0.165 degree movement)

Additional tests performed by LTVE were intended to provide information on the dymanic characteristics of a "typical" pedestal. The performance specifications are listed in Table 4-1. An acceptable pedestal may deviate up to (0.4°) degree and this does not take into consideration any input errors from the autotracker position or boresight.

As a final review the author will conclude this study by listing the accumulative effect of "acceptable" errors on tracking accuracy. These errors are generated by the autotracker, linkages, boresight adjustment, synchro follow-up assembly, and "typical" dynamic pedestal performance. Linkage adjustment is the only assumed error (0.050°). The results are listed on the following page.

Error (deg.)	
Autotracker (AT)	0.100
Linkage (AT)	0.050
Boresight (AT)	0.100
Synchro follow-up assembly (AT).	0.103
Pedestal performance (dynamic)	0.400
Overall tracking error	0.753

TABLE 4-1

PEDESTAL PERFORMANCE SPECIFICATIONS

PARAMETER	SPECIFICATIONS
Instrument Group Weights	40. to 153. lb
Instrument Group Inertias	3.3 to 35.1 slug-Ft^2
Acceleration	3 RAD/SEC^2=172 DEG/SEC^2 Minimum
Velocity, Slew	45. DEG/SEC Minimum
Velocity, Track	5. DEG/SEC Maximum
Total Error at 5 DEG/SEC	0.4 DEG Maximum

CONSISTING OF

	RANDOM DEG	ONE-SIDED DEG
Platform CT	0.1	
Platform CX	0.1	
Amplifier Null	0.025	
Motor Threshold		0.048
Static Load		0.039
Dynamic		0.2
	0.103	0.287

$$ERR_{tot} = \sqrt{0.1^2 + 0.025^2} + 0.287$$

$$= 0.103 + 0.287 = 0.390 \text{ DEG}$$

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The author's conclusions parallel the sequence of events in this study. They begin with the path of angular transfer and conclude with overall tracking accuracy. From these conclusions the author recommends changes for improved tracking accuracy and boresight. The last recommendation is for distribution.

CONCLUSIONS

1. The path of angular transfer contains an excessive number of transition points (35). Every point of transition (electrical and mechanical) increases the probability of tracking error.

2. Presently there is no convenient way to accurately determine instrument boresight. System errors may go undetected for long periods of time and degrade mission effectiveness.

3. Linkage adjustment and dimensions are critical for accurate angular transfer and any error will contribute to nonlinear tracking.

4. The synchro follow-up assembly boresight adjustment is unsatisfactory. It is inaccurate, difficult to adjust, and requires special equipment.

5. Instrument boresight procedures are complex, limited, and time consuming because of the need for radiant targets and camera downloading.

6. The probability of servo system failure is increased by depending on the operation of two parallel servo loops. This applies only to instrument loads in excess of 153 pounds.

7. Failure in one of the two parallel servo loops will degrade overall tracking accuracy. This applies to all instrument loads under 153 pounds.

8. Pedestal firmness is determined by the balance between servo loop error voltages. Any imbalance (out of null) will result in a loose pedestal.

9. Two parallel single speed servo systems have a higher overall tracking accuracy when compared to a single speed system. This is based on a mean average $\left[(CT-2)+(CT-1)\right]\div 2$.

10. The overall tracking accuracy of the RC-135-S optical tracking system is not sufficient for a one degree (1°) field of view instrument.

Recommendations

Figures 5-1 and 5-2 illustrate the author's recommendations for design changes in the synchro follow-up assemblies and boresight adjustments. The proposed interconnections are illustrated in Figure 5-3. The specific changes and benefits are listed below:

1. Autotracker and pedestal linkages are eliminated. They are replaced with a three inch antibacklash drive gear. This gear is mounted directly onto the autotracker and pedestal pivot point. The number of transition points between pivot point and rotor are reduced and the need for adjustments eliminated.

2. One servo loop is eliminated by feeding both servo amplifiers in parallel from one pedestal control transmitter (CT). Error signals are then identical and result in assured pedestal firmness. System reliability is increased for instrument loads in excess of 153 pounds because they depend on proper operation of both servo loops. The number of transition points is reduced from thirty-five (35) to sixteen (16).

3. One autotracker control transmitter (CX) is provided for each pedestal (8). Normally, one CX is assigned to three or five pedestals. Independent servo loops increase system reliability and prevent interaction.

Figure 5-1

Autotracker Synchro Follow Up Assembly (Proposed)

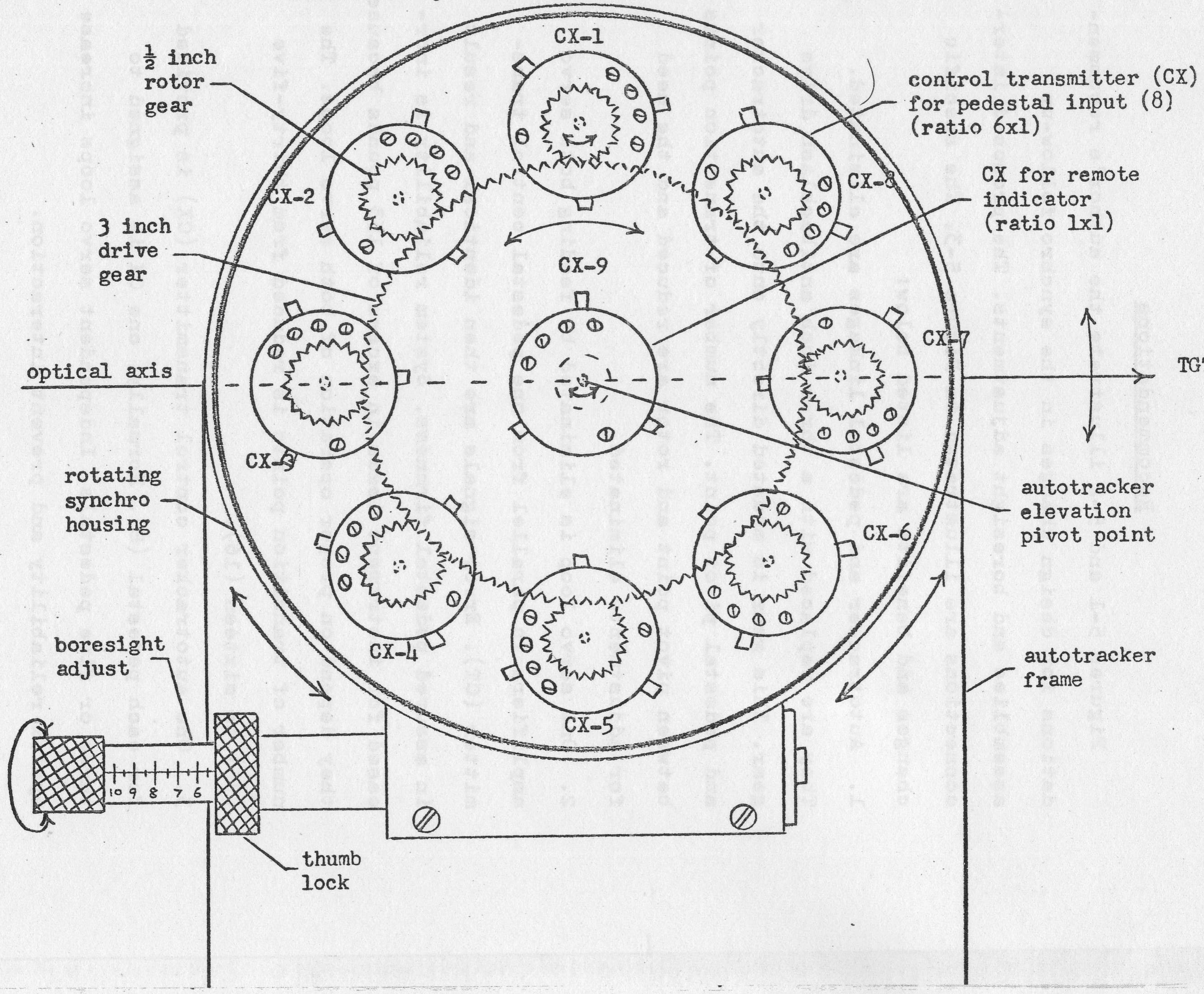


Figure 5-2

Pedestal Synchro Follow Up Assembly

(Proposed)

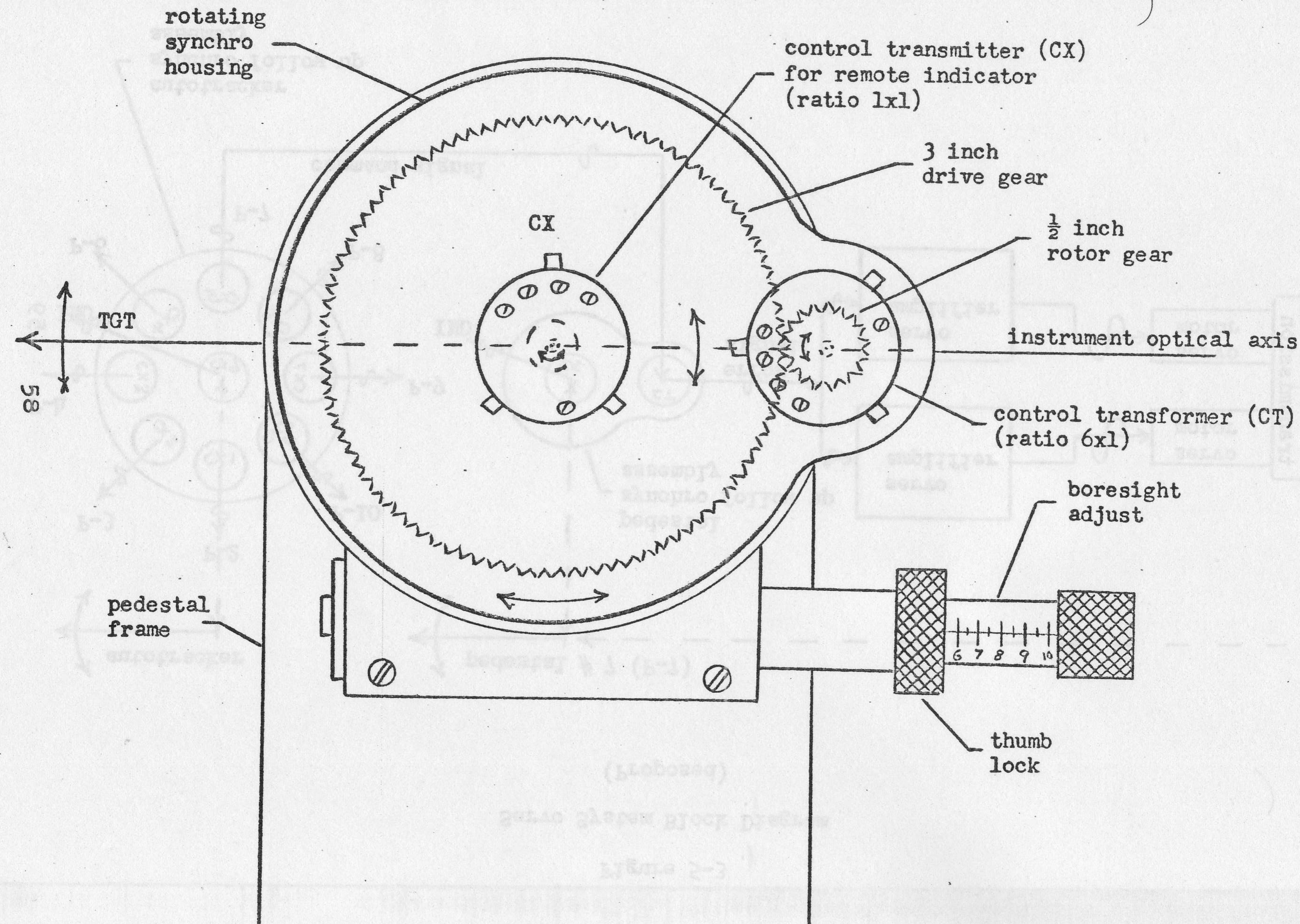
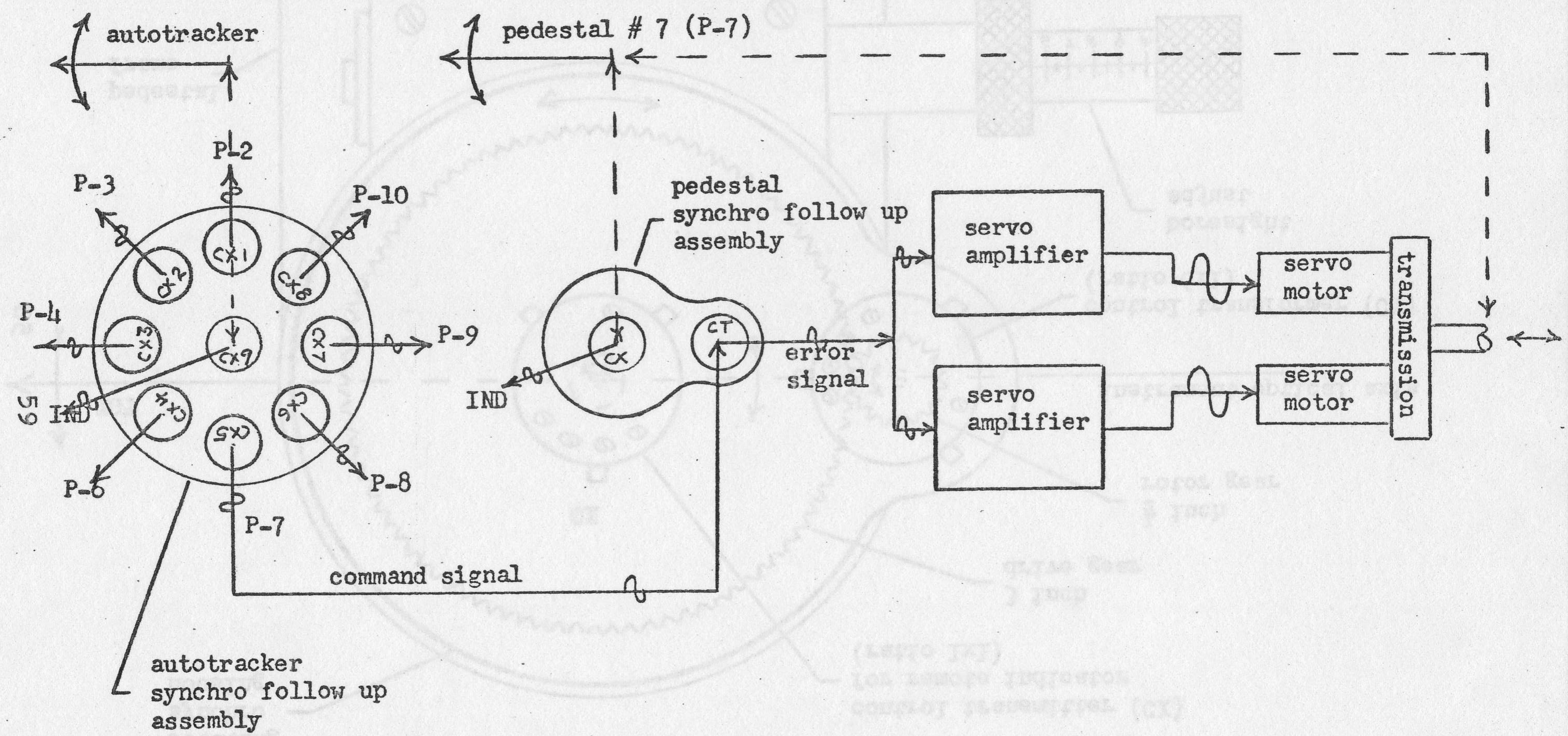


Figure 5-3

Servo System Block Diagram

(Proposed)



4. Synchro rotor speed is increased from (1x1) to (6x1). This is accomplished by using a three inch (3") drive gear and one-half inch ($\frac{1}{2}$") rotor gear. Antibacklash gears are used. All gear train and synchro errors (mechanical and electrical) are reduced by a factor of six. For example, assume the autotracker synchro follow-up assembly induces a twelve minute (12') tracking error. This means the pedestal control transformer rotor must rotate through twelve minutes (12') to effect a null. With a speed ratio of six to one (6x1) null is achieved by rotating the pedestal through only two minutes (2'). The results are two minutes (2') tracking error instead of twelve (12').(2:94) This system would reduce the tracking errors illustrated in Figures 4-3 and 4-4 by a factor of six.

A gear ratio of six to one (6x1) is used to prevent the problems associated with multiple null points of a double speed system.(2:95) A six to one ratio (6x1) generates six true nulls. Pedestal movement is limited to a sixty degree (60°) arc and therefore should be no problem. ($6 \times 60^{\circ} = 360^{\circ}$) Note: The remote indicator transmitters (CX) are driven at a one to one (1x1) ratio to preclude indicator modifications.

5. The boresight adjustment is replaced with a thumb

looking micrometer movement. Adjustments will be smoother because of increased leverage and finer gearing. Special equipment is not required and settings may be recorded.

6. A variable power (2x8) sighting scope is mounted on all instruments (including autotracker) and aligned with each optical axis. Cameras will not require downloading for boresight adjustments and passive targets (nonradiating) may be used by manually directing the autotracker. Real time tracking accuracy may be checked by observing operational events through the scopes.

7. One copy of this report should be forwarded to Ling Tempco Vought Electrosystems, Inc. (LTVE) because this company is responsible for all RC-135-S optical modifications. The address to which the study should be sent is:

Mr. John V. Tumas
Optical Systems Engineer
Unit 54511
LTVE
P.O. Box 1056
Greenville, Texas 75401

APPENDIX A

STATIC ACCURACY TEST

APPENDIX A

STATIC ACCURACY TEST

Chapter IV of this research paper made reference to a pedestal synchro follow-up assembly static accuracy test conducted by LTVE. The procedures for this test are as follows:

> ... two synchro packages (S/N 10 and 8) were tested individually for electrical and mechanical errors. They were tested on an azimuth turntable.
>
> The turntable was first calibrated ... by mounting on it a theodolite and turning it through 360 degrees in five degree steps. The theodolite was pointed at a distant target and read at each five degree point. A curve of error vs azimuth angle for the turntable thereby was obtained. This curve was used to correct the synchro package static accuracy readings...
>
> In order to perform the test, the package was mounted on the turntable, and the centerline of the package shaft was made approximately coincident with the centerline of the turntable (within about 0.015 inch). A lever arm was attached to the shaft of the package and restrained at the other end. A mirror was attached to the shaft and shot with the theodolite to be correct for any small shaft motions. The correction curve was subtracted from the readings obtained..... A command synchro was used to indicate null on the CT's. A Theta Synchro Error Bridge was used to read the command synchro, and one to read the package CX.

The test was performed by turning the turntable through 360 degrees at ten degree increments. The CT's were nulled by adjusting the command synchro. The angles of the command synchro and package CX were read with the Theta bridges.

The plots of test results ... were corrected, as previously stated, by subtracting turntable error and shaft motion error. (13:96)

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